1 UNIT

Introduction and Solar Cells

Part-1 ..... **(5M - 18M)**

- *Introduction : Various Non Conventional Energy Resources*
- *Availability*
- *Classification*
- *Relative Merits and Demerits*

A. Concept Outline : Part-1 ..... 5M
B. Long and Medium Answer Type Questions 5M

Part-2 ..... **(18M - 28M)**

- *Theory of Solar Cells*
- *Solar Cell materials*
- *Solar Cell Array*
- *Solar Cell Power Plant*
- *Limitations*

A. Concept Outline : Part-2 ..... 18M
B. Long and Medium Answer Type Questions 18M

PART-1

Introduction : Various Non Conventional Energy Resources Availability, Classification, Relative Merits and Demerits.

CONCEPT OUTLINE : PART-1

Non Conventional Energy Resources : These are the sources of energy which are inexhaustible, and can be used to produce energy again and again.

Example : Wind energy, Geothermal, Ocean energy, Solar energy and Tidal energy.

Classification : The non conventional (renewable) energy are classified as :

1. Solar energy,
2. Ocean thermal energy,
3. Wind energy,
4. Tidal energy,
5. Wave energy,
6. Marine current,
7. Hydro power,
8. Geothermal energy,
9. Biomass,
10. Wood and charcoal energy, and
11. Direct energy conversion resources :
    a. Fuel cell,
    b. Magneto hydrodynamics,
    c. Solar cells, and
    d. Thermoelectric and thermoionic converter.

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 1.1. Describe commercial and non commercial energy sources.

Answer

A. Commercial Energy Sources :

1. Those energy sources which are available in the market and which can be purchased from the producing agency are known as commercial energy sources.

2. These sources form the basis of industrial, agricultural, transport and commercial development in the modern world.
3. In the industrialized countries, commercialized fuels are predominant source not only for economic production, but also for many household tasks of general population.

Examples : Coal, oil, natural gas, petroleum products etc.

B. Non Commercial Energy Sources :

1. Those energy sources which are not available in the commercial market for a purchase are known as non commercial energy sources.
2. These sources are often ignored in energy accounting.

Examples : Firewood, agro-waste, animal dung, solar energy, wind energy etc.

Que 1.2. What are the conventional and non conventional energy sources ? Describe the fossil fuel as a conventional energy source.

Answer

A. Conventional (Non Renewable) Energy Sources : These are the sources of energy which are exhaustible *i.e.*, cannot be replaced if once they are used.

Example : Coal, Petroleum products, Natural gas etc.

B. Non Conventional (Renewable) Energy Sources : These are the sources of energy which are inexhaustible *i.e.*, can be used to produce energy again and again.

Example : Sun, Water, Animal dung, Agro-waste etc.

C. Fossil Fuel as a Conventional Energy Source : Some of the fossil fuels are discussed below :

a. Coal Energy :

1. Coal is a conventional energy source.
2. It is formed due to degradation of trees and plants buried under layers of silt.
3. It is composed of mainly carbon and hydrocarbons.
4. Coal is found in Jharkhand, U.P., M.P., Bihar etc. in India.
5. Uses of coal :
   - i. Coal is used to generate electricity. Power plants use coal for heating the water to generate steam, which runs the turbines to generate electricity.
   - ii. Various industries use heat obtained from coal in making plastics, tar, synthetic fiber, etc.
   - iii. Coal is heated in furnace to make coke, which is used to melt iron for making steel.

6. Environmental problems :
   - i. Due to combustion of coal, carbon dioxide is produced which is responsible for causing global warming.
   - ii. Coal also produces sulphur dioxide which is a cause for acid rain.

b. Natural Gas :

1. Natural gas formed by decomposition of dead animals and plants buried under the earth.
2. It is mainly composed of methane (CH_4) with small amount of propane and ethane.
3. Natural gas is the cleanest fossil fuel.
4. Uses of natural gas :
   - i. It is used as a domestic and industrial fuel.
   - ii. It is also used in thermal power plants for generating electricity.
5. Advantages :
   - i. Natural gas has a high calorific value and it burns without any smoke.
   - ii. It can be easily transported through pipelines.

Que 1.3. Give a brief review of various sources of renewable energy.

OR

Discuss renewable forms of energy. Highlight their merits and demerits. **UPTU 2012-13, Marks 10**

OR

What do you mean by non conventional energy resources ? Discuss briefly. **UPTU 2011-12, Marks 10**

Answer

Various Sources of Renewable Energy :

A. Solar Energy :

1. Solar energy is a clean, cheap and abundantly available renewable energy and it is also the most important of the non conventional sources of energy because it is non-polluting and, therefore helps in decreasing the green house effect.
2. Solar energy can be used as :
   - a. By direct conversion to a fuel by photosynthesis.
   - b. By direct conversion to electricity by photovoltaic.
   - c. By conversion to electricity via thermo-electric power system.

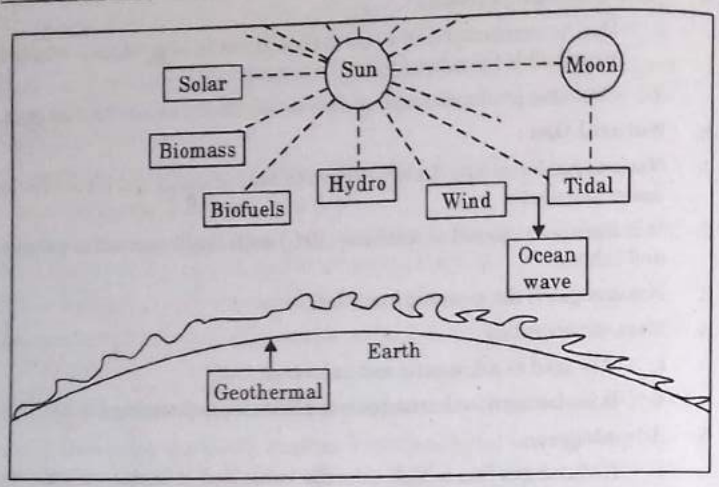


Fig. 1.3.1. Renewable sources of energy.

3. The sun releases the enormous amount of energy due to continuous fusion reaction taking place inside the sun.
4. The sun sends out the energy in the form of radiations at the rate of 3.7×10^{20} MW.
5. However, the energy intercepted by the earth is about 1.85×10^{11} MW.
6. This energy available is several times more than all the energy produced and consumed in the world.

a. Merits of Solar Energy :

i. Noiseless operation.
ii. Occupies less space on floor as there is no need of storage vessels.
iii. Cheaper initial cost and no need of containers to store the fuel.

b. Demerits :

i. Solar equipments fail to work in nights, cloudy days or rainy season.
ii. Large space is required for the collection of solar energy at a useful rate.

B. Biomass :

1. Green plants trap solar energy through the process of photosynthesis and convert it into organic matter. This organic matter is known as biomass.
2. Wood, charcoal, agricultural waste produces the bio-energy after burning, and cow dung, garbage are anaerobically decomposed to obtain the energy.
4. Dried animal dung or cattle dung cakes are used directly as fuels in rural area but it produces smoke and has low efficiency of burning.

a. Merits :

i. Cost of obtaining bio-energy through plantations is lesser than cost of obtaining energy from fossil fuels.
ii. Plants ensure a continuous supply of energy due to their continuous growth.
iii. Growth of biomass consumes more CO_2 than is released during combustion of biomass besides producing the atmosphere–purifying oxygen as a by–product of the photosynthesis process.

b. Demerits :

i. Accumulation of water in the pipe line and need to remove it at periodic intervals.
ii. Inefficient designing of gas appliances.
iii. Seasonal variation in gas production due to lack of temperature control and poor insulation of the plant.

C. Hydro Energy :

1. It is a renewable energy source, which is used to generate electricity.
2. Hydropower is obtained from water flow or falling water from a height.
3. Water stored behind dam and at a height has a lot of potential energy which is converted into mechanical and electrical energy.
4. The water is released gradually and is allowed to fall under the gravitational force and drive which rotate hydraulic turbines.
5. The generators attached with turbine produce the electricity.

a. Advantage :

i. Hydropower does not pollute the water or the air during operation and no waste products are formed.

b. Limitation :

i. The generation of electricity by hydroelectric power plants results in pollution and ecological disturbance like flooding situation and adverse effects on flora and fauna.

D. Wind Energy :

1. Wind energy is a renewable source of non polluting energy and it has tremendous potential which if harnessed, can easily satisfy the energy demands of a country.
2. Estimates reveal that 2 % of the total solar energy falling on earth is converted to kinetic energy in the atmosphere.
3. 30 % of this kinetic energy occurs in the lowest 1000 m of elevation *i.e.*, wind in the lowest kilometer has maximum kinetic energy which can be converted into mechanical energy which in turn can be utilized to generate electricity or to perform some other useful work.

4. Since, the energy possessed by wind is by virtue of its motion, so the device used to extract its energy should be capable of slowing down the wind.

a. Merits :

i. Abundance availability for no price.

ii. Useful at remote places also for electricity generation.

iii. Non polluting and eco-friendly.

b. Demerits :

i. Less favourable in city locations as the wind is available at higher locations.

ii. It is unreliable and intermittent. It is not available regularly.

iii. Present day wind energy systems are a source of immense noise pollution.

E. Tidal Energy :

1. Gravitational pull by sun and moon result in the tides.
2. This type of energy can be harnessed by constructing the tidal barrage.
3. Energy can be harnessed from high as well as from low tides.
4. During high tides, the sea water flows into the reservoir of the barrage and operates the turbine which in turn produces electricity, by rotating generators.
5. During low tides, the water stored in the reservoir flows into the sea and again operates the turbine.
6. In this way the energy can be harnessed from high and low tides.

a. Merits :

i. Very less area is required because they are on bays.

ii. It is free from pollution as it does not use any fuel.

iii. It does not produce any unhealthy waste like gases, ash, refuse, etc.

b. Demerits :

i. Tidal power plants can be developed only if natural sites are available.

ii. The capital cost of the plant is high.

iii. Utilization of tidal energy on small scale has not yet proved economical.

F. Ocean Thermal Energy :

1. *OTEC i.e.*, ocean thermal energy conversion plants convert the heat of the ocean into electrical energy, with the help of temperature difference.
2. The large temperature difference between warm surface sea water (28 - 30 °C) and cold deep sea water (5 - 12 °C) is used to generate electricity, with the help of ocean thermal energy conversion system.

a. Merits :

i. The OTEC process exploits the temperature difference between the warm surface and cold bottom water to produce electricity. In India, the conditions for operation of OTEC plant are favourable because of this temperature different that remains constant throughout the year.

ii. Inexpensive transmission of electricity is possible provided the OTEC plant is less than 30 km from the sea shore.

b. Demerits :

i. At greater distance (from plant to sea shore) the transmission cost of electricity is increased.

ii. OTEC technology is in infant stage.

iii. OTEC technology is costly and difficult.

G. Wave Energy :

1. The motion of the sea surface in the form of wind waves forms a source of energy.
2. Floating propellers are placed in shallow waters, near the shores and due to motion of the waves, the propellers also get the motion and this kinetic energy can be used to drive turbines.
3. This is cheap, clean and inexhaustible source of energy.

a. Merits :

i. Ocean wave energy source is renewable and free of cost, hence its importance will increase with time.

ii. Waves are continuous. They come and go between 6 second.

iii. Collector size of wave machines is comparatively smaller than solar devices.

b. Demerits :

i. Corrosion of materials used in plant.

ii. Marine growth of algae in the plant.

iii. Obstruction to ships.

H. Geothermal Energy :

1. The energy harnessed from the hot rocks present inside the earth is called as geothermal energy.
2. There is an increase in the temperature of the earth with increasing depth below the surface.
3. The fission of radioactive material naturally occurring in the rocks increases the temperature of the earth as we move down from the earth's surface.
4. Hot molten rocks called 'magma' are present in the core of the earth. This causes sometimes volcanic action.
5. This hot steam is used to operate turbines to generate electricity.
6. Artificially it can also be harnessed with the help of pipes by drilling the hot rocks, which make the hot water to gush out through pipes which turns the turbine of the generator to produce electricity.

a. Merits :

i. It is cheap and clean source of energy.

ii. Geothermal plants require little land area.

b. Limitations :

i. Air pollution results in case of release of gases like H_2S, NH_3 present in the steam waste.

ii. Noise pollution results from the drilling operations.

K. Hydrogen Energy :

1. Hydrogen is considered as an alternative future source of energy.
2. It is a non conventional energy resource.
3. Hydrogen energy has a tremendous potential because it can be produced from water which is available in abundance in nature.
4. In sun's core, hydrogen atoms combine to form helium atom which is known as fusion reaction.
5. It gives the radiant energy which sustains the life on the earth.
6. Hydrogen can be separated from water by means of electrical energy.
7. It can also be obtained from fossil fuels.

a. Advantages :

i. Hydrogen energy has very high energy content.

ii. Its burning is non-polluting.

b. Disadvantages :

i. Highly flammable.

ii. It is more expensive.

Que 1.4. Discuss the primary and secondary energy sources. Also describe the future of non conventional energy sources in India.

UPTU 2013-14, Marks 05

Answer

A. Primary Energy Resources :

1. These resources are obtained from the environment.

Example : Fossil fuels, solar energy, hydro energy and tidal energy.

2. These resources can further be classified as :

i. a Conventional Energy Sources :

Example : Thermal power.

b. Non Conventional Energy Sources :

Example : Wind energy, geothermal, ocean energy, solar energy and tidal energy.

ii. a. Renewable : These sources are being continuously produced in nature and are inexhaustible.

Example : Wood, wind energy, biomass, biogas, solar energy etc.

b. Non Renewable : These are finite and exhaustible.

Example : Coal, petroleum etc.

B. Secondary Energy Resources : These resources do not occur in nature but are derived from primary energy resources.

Example : Electrical energy from coal burning, H_2 obtained from hydrolysis of H_2O.

C. Future of Non Conventional Energy Sources :

1. Non conventional energy sources consist of those energy sources that are infinite, natural, and restorable.

For Example : Tidal energy, solar energy, and wind energy are non conventional sources of energy.

2. The application of tidal energy and wind energy was operational in the form of energy sources long back when mineral oil, coal, and natural gas were not broadly introduced as conventional sources of energy.
3. In the beginning, windmills were utilized for taking out water and pounding grains. Running water and wind were applied for direction finding.
4. Currently, some of the important and widely used non conventional sources of energy are tides, wind, solar, geothermal heat, and biomass comprising animal waste, agricultural waste, and human body waste.
5. To bridge the deficits, and cater to future demand the country needs additional power generation capacity of approximately 1,00,000 MW over the next few years.
6. National goal of electrical power generation by 2012 is 2,00,000 MW to ensure reliable and quality power to all citizens.
7. Out of this about 10,000 MW will be sourced from non conventional sources.
8. Electrification of rural areas is very important for uniform development of the country.
9. There are about 6 lakh (10 lakh = 1 million) villages in the country.
10. An estimated 1,00,000 villages are still to be electrified. Of these, there are about 25,000 villages in remote and difficult areas, which are unlikely to be electrified by conventional grid extension.
11. Most of these villages are in hills, forests, deserts and islands.
12. Government has decided that all the remaining unelectrified villages in the country should be electrified in a time bound manner.
13. The remote villages and hamlets are to be electrified through decentralized generation using non conventional energy sources such as solar energy, biomass and micro / mini / small hydro resources.

14. It is proposed to electrify all such villages by the year 2007 and all households by 2012. The technology to be used will depend upon the size of the village and the resources available locally.

Que 1.5. What are the advantages and limitations of non conventional or renewable energy resources ?

Answer

A. Advantages :

1. Renewable energy is an indigenous resource available in considerable quantities to all developing nations and capable, of having a significant local, regional or national economic impact. The use of renewable energy could help to conserve foreign exchange and generate local employment if conservation technologies are designed, manufactured, assembled and installed locally.
2. Several renewable resources are financially and economically competitive for certain applications, such as in remote locations, where the costs of transmitting electrical power or transporting conventional fuels are high, or in those well endowed with biomass, hydro or geothermal resources.
3. Since conversion technology tends to be flexible and modular, it can usually be rapid deployed. Other advantages of modular over very large individual unit include easy in adding new capacity, less risk in comparison with 'lumpy' investments, lower interest on borrowed capital because of shorter lead times and reduced transmission and distribution costs for dispersed rural locations.
4. Rapid scientific and technological advantages are expected to expand the economic range of renewable energy applications over the next 8-10 years, making it imperative for international decision makers and planners to keep awareness of these developments.

B. Limitations :

1. Inadequate documentation and evaluation of past experience, a scarcity of validated field performance data and a lack of clear priorities for future work.
2. Weak or non-existent institutions and policies to finance and commercialize renewable energy systems.
3. Technical and economic uncertainties in many renewable energy systems, high economic and financial costs for some systems in comparison with conventional supply option and energy efficiency measures.
4. Skeptical attitudes towards renewable energy systems on the part of the energy planners and a lack of qualified personnel to design, manufacture, market, operate and maintain such systems.

5. Inadequate donor coordination in renewable energy assistance activities, with little or no information exchange on successful and unsuccessful projects.

Que 1.6. What is MNRE ? What are the mission and functions of it ? Define and explain renewable and non-renewable resources. Mention at least one energy resource in each category.

UPTU 2014-15, Marks 10

Answer

A. MNRE :

1. The Ministry of New and Renewable energy (MNRE) is the nodal ministry of the government of India for all matters relating to new and renewable energy.
2. The broad aim of the ministry is to develop and deploy new and renewable energy for supplementing the energy requirements of the country.
3. Creation CASE and ministry :
   a. Commission for Additional Sources of Energy (CASE) in 1981.
   b. Department of Non Conventional Energy sources (DNES) in 1982.
   c. Ministry of Non Conventional Energy Sources (MNES) in 1992.
   d. Ministry of Non Conventional Energy Sources (MNES) renamed as ministry of New and Renewable Energy (MNRE) in 2006.
4. The role of new and renewable energy has been assuming increasing significance in recent times with the growing concern for the country's energy security.
5. Energy self-sufficiency was identified as the major driver for new and renewable energy in the country in the wake of the two oil shocks of the 1970s.
6. The sudden increase in the price of oil, uncertainties associated with its supply and the adverse impact on the balance of payments position led to the establishment of the commission for additional sources of energy in the department of science and technology in March 1981.
7. The commission was charged with the responsibility of formulating policies and their implementation, programmes for development of new and renewable energy apart from coordinating and intensifying *R & D* in the sector.

B. MISSION :

1. The Jawaharlal Nehru national solar mission was launched on the 11th January, 2010 by the Prime Minister.
2. The mission has set the ambitious target of deploying 20,000 MW of grid connected solar power by 2022 is aimed at reducing the cost of solar power generation in the country through :

i. Long term policy,
ii. Large scale deployment goals,
iii. Aggressive *R* & *D*, and
iv. Domestic production of critical raw materials, components and products, as a result to achieve grid tariff parity by 2022.

3. Mission will create an enabling policy framework to achieve this objective and make India a global leader in solar energy.

C. Renewable and Non Renewable Resources : Refer Q. 1.2, Page 6M, Unit-1.

Que 1.7. What are conventional and non conventional energy resources ? Discuss the prospects of non conventional energy sources in India. **UPTU 2014-15, Marks 10**

Answer

A. Conventional and Non Conventional Energy Resources : Refer Q. 1.2, Page 6M, Unit-1.

B. Prospects of Non Conventional Energy Sources in India :

1. India is heavily dependent on fossil sources of energy for most of its demand.
2. This has necessitated the country to start aggressively pursuing alternative energy sources – solar, wind, biofuels, and small hydro and more.
3. India is the 4th largest country with regard to installed power generation capacity in the field of renewable energy sources.
4. Wind, hydro, biomass and solar are main renewable energy sources.
5. India has tremendous potentialities to harness the much-needed energy from renewable sources.
6. The country has an estimated renewable energy potential of around 90000 MW from commercially exploitable sources; wind, 48500 MW; small hydro, 15000 MW and biomass/bioenergy, 25000 MW.
7. In addition, India has the potential to generate 35 MW per square km using solar photovoltaic and solar thermal energy.
8. India is among top 5 destinations worldwide for solar energy development.
9. Government has launched Jawaharlal Nehru National Solar Mission which aims to generate 20 GW by 2022.
10. Wind energy is the fastest growing renewable energy sector.
11. Wind energy, with an installed capacity of nearly 15 GW, accounts for the bulk of installed renewable energy capacity in India making it fifth top country in the world, after USA, China, Germany, and Spain in terms of installed capacity.
12. Coastal areas of Gujarat, Tamil Nadu, Andhra Pradesh, as well as vast areas of Maharashtra and Madhya Pradesh provide a good potential for its development.
13. Globally, India is in the fourth position in generating power through biomass and has the potential to become a world leader in the utilisation of biomass.
14. Biomass power projects with an aggregate capacity of 773.3 MW through over 100 projects have been installed in the country.
15. For the last 15 years, biomass power has become an industry attracting annual investment of over 1000 billion, generating more than 9 billion unit of electricity per year.
16. More than 540 million tonnes of crop and plantation residues are produced every year in India and a large portion is either wasted, or used inefficiently.
17. By using these surplus agricultural residues, by conservative estimates more than 16000 MW of grid quality power could be generated through biomass.
18. With numerous rivers and their tributaries in India, small hydro RE (< 25 MW) presents an excellent opportunity with an estimated potential of 15000 MW with only 17 percent of this sector exploited so far.
19. Over 674 projects aggregating to about 2558.92 MW generating capacity has been set up in the country as on 31.12.2009. Most of the potential is in Himalayan states as river-based projects and in other states on irrigation canals.

B. Energy from Wastes :

1. The rising piles of garbage in urban areas caused by rapid urbanization and industrialization throughout India represent another source of non conventional energy.
2. An estimated 50 million tonnes of solid waste and approximately 6000 million cubic metres of liquid waste are generated annually in the urban areas of India.
3. Good potential exists for generating approximately 2600 MW of power from urban and municipal wastes and approximately 1300 MW from industrial wastes in India.

C. Biofuels :

1. The GOI recently mandated the blending of 10 percent fuel ethanol in 90 percent gasoline.
2. This mandate has created an approximately 3.6 billion-liter demand for fuel ethanol in blend mandate to the entire country.

3. This significant demand growth creates a tremendous manufacturing opportunity for the fuel ethanol industry seeking to expand its investments internationally.

PART-2

Theory of Solar Cells, Solar Cell Materials, Solar Cell Array, Solar Cell Power Plant, and Limitations.

CONCEPT OUTLINE : PART-2

Solar Cells : Energy conversion devices which are used to convert sunlight to electricity by the use of the photovoltaic effect are called solar cells. A single converter cell is called a solar cell or, more generally, a photovoltaic cell, and combination of such cells ; designed to increase the electric power output is called a solar module or solar array.

Solar Cell Materials : The solar cells are made of various materials. Silicon is the most commonly used material for solar cells. A variety of compound semiconductors are to be used to manufacture thin film solar cell. These materials are $CuInSe_2$, CaS, CdTe, Cu_2S, InP, GaAs, Zinc Telluride (ZnTe), AlSb (aluminium antimonide).

Types of Solar Cells : According to type of crystal, the solar cells are of three types :

a. Monocrystalline silicon cells (band gap 1.12 eV),
b. Polycrystalline silicon cells (band gap 1.12 eV), and
c. Amorphous silicon cell (band gap 1.75 eV).

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 1.8. **Write short note on solar cells and its materials.**

Answer

A. Solar Cells :

1. Photovoltaic energy is the conversion of sunlight into electrical energy through a photovoltaic cell, commonly called a solar cell.
2. Solar cells are the solid state electronic device used to convert the electromagnetic energy of solar radiation directly into direct current electricity. This conversion takes place inside the cell.
3. When sunlight strikes the solar cell, electrons are knocked loose. They move towards the treated front surface. An electron unbalance is created between the front and back. When the two surfaces are joined by a

connector, like a wire, an electric current flows between the negative and positive sides.

4. These individual solar cells are arranged together in an array.

B. Solar Cell Materials :

1. The solar cell is made of different material and silicon and silicon is one used for nearly 90 % applications.
2. The choice of material depends on the band energy gap, efficiency and cost.
3. The maximum efficiency of solar cell is achieved with the band gap energy of 1.12 eV-2.3 eV.
4. The various materials like aluminum silicon, Si (1.12eV), Aluminium antimonide, AlSb (1.27 eV), Cadmium telluride, CdTe (1.5 eV), Zink telluride, ZnTe (2.1 eV), Cadmium sulphide, CdS (2.42 eV) etc. are the materials suitable for solar cell.
5. The smaller the energy gap, the large number of photon of solar spectrum will be useful to produce the required energy for electrons to jump the forbidden band gap.

Que 1.9. **Write short note on :**

A. Principle of solar photovoltaic, and
B. Photovoltaic effect.

Answer

A. Principle of Solar Photovoltaic :

1. It is a field of solar energy utilization by which solar radiation is converted into electrical energy using a device called photovoltaic cell or solar cell.
2. A solar cell is made up of a semiconductor material like silicon (Si) or gallium arsenide GaAs.
3. In semiconductors, atoms carry four electrons in the outer valence orbit, some of which can be dislodged to move freely in the materials, if extra energy is supplied.
4. Then, a semiconductor attains the property to conduct the current. This is the basic principle on which the solar cell works and generates power.

B. Photovoltaic Effect :

1. When a solar cell is illuminated, electron-hole pairs are generated and the electric current I is obtained.
2. I is the difference between the solar light generated current I_L and the diode dark current I_j.
3. Mathematically :

$$I = I_L - I_j$$

$$= I_L - I_o\left[\exp\left(\frac{eV}{KT}\right) - 1\right]$$

Where,
I_o = Saturation current,
e = Electronic charge,
T = Absolute temperature, and
K = Boltzmann's constant.
$= 1.38 \times 10^{-23}$ J/K.

Que 1.10. Classify solar cells. Derive an expression for maximum power output and efficiency of a solar cell.

UPTU 2011-12, Marks 10

Answer

1. According to type of crystal, the solar cells are of three types :
   a. Monocrystalline silicon cells (band gap 1.12 eV),
   b. Polycrystalline silicon cells (band gap 1.12 eV), and
   c. Amorphous silicon cells (band gap 1.75 eV).

a. Monocrystalline Silicon Cell :

1. In monocrystalline silicon cells, silicon is doped with boron to produce p-type semiconductor.
2. Monocrystalline rods are extracted from silicon and then sawed into thin plates or wafers.
3. The upper layer of the wafers is doped with phosphorous to produce n-type semiconductor. This becomes p-n junction.
4. Maximum efficiency is 24 %.

b. Polycrystalline Silicon Cell :

1. In polycrystalline cells, liquid silicon is poured into blocks that are sawed into plates.
2. During solidification of the material, crystal structures of varying sizes are formed.
3. The size of crystallites mainly depends upon the cooling condition. If the molten silicon is cooled very slowly, the crystallites of larger size are obtained.
4. The silicon solar cells made from polycrystalline silicon are low cost but low efficiency (maximum efficiency is 17.8 %).

c. Amorphous Silicon Cell :

1. If a silicon film is deposited on glass or another substrate material, this is so called amorphous or thin layer cell.
2. The layer thickness is less than 1 μm, so production costs are lower due to the low material costs.

3. However, the efficiency of amorphous cells is much lower than that of the other cells. Because of this, they are primarily used in low power equipment such as watches, pocket calculators etc. Maximum efficiency is 13 %.

A. Efficiency of Solar Cell :

1. The electrical characteristics of a solar cell are expressed by the voltage current (V-I) curves plotted under a given illumination and temperature conditions as shown in Fig. 1.10.1.

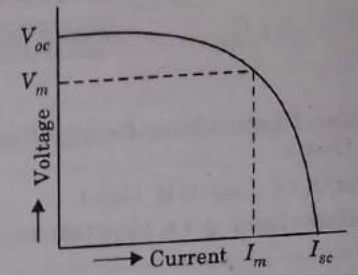


Fig. 1.10.1. Voltage-current (V-I) characteristic of a solar cell.

2. In Fig. 1.10.1, the maximum useful power of the cell is represented by the rectangle with the largest area.
3. When the cell yields maximum power, the current and voltage are represented by the symbols I_m and V_m respectively.
4. Leakage across the cell increases with temperature which reduces voltage and maximum power.
5. Cell quality is maximum when the value of 'fill factor' approaches unity, where the fill factor (FF) is expressed as

$$FF = \frac{I_m V_m}{I_{sc} V_{oc}}$$

Where,
V_{oc} = Open circuit voltage, and
I_{sc} = Short circuit current.

6. Maximum efficiency of a solar cell is defined as the ratio of maximum electric power output to the incident solar radiation.

Mathematically :

$$\eta_{max} = \frac{I_m V_m}{I_s A_c}$$

Where,
I_s = Incident solar flux, and
A_c = Cells area.

7. Maximum power output,

$$P_{max} = V_{max\,P} \times I_{max\,P}$$

Que 1.11. **Describe principle of solar photovoltaic conversion. Discuss the limitations of solar photovoltaic energy conversion.**

UPTU 2012-13, Marks 10

OR

Describe the principle of solar photovoltaic energy conversion. Classify solar cells. What are the materials used in solar cells ? Also discuss the factors that limit the efficiency of the solar cells.

UPTU 2014-15, Marks 10

Answer

A. Principle of Solar Photovoltaic Energy Conversion : Refer Q. 1.9, Page 19M, Unit-1.

B. Solar Cells : Refer Q. 1.8, Page 18M, Unit-1.

C. Solar Cell Materials : Refer Q. 1.8, Page 18M, Unit-1.

D. Limitations :

1. When photons of light energy from the sun strike the cell, some of them (30 %) are reflected (since reflectance from semiconductors is high).
2. Photons of quantum energy $h\upsilon < Eg$ cannot contribute to photoelectric current production (h is the Planck's constant and υ the frequency).
3. Photovoltaic cells are exposed directly to the sun. As the temperature rises, leakage across the cell increases. Consequently, there is reduction in power output relative to input of solar energy.
4. Incident active photons produce electron-hole pairs with high quantum efficiency. Better cell design is required to ensure 95 % absorption.
5. The semiconductor with optimum band gap should be used for maximum efficiency.

Que 1.12. **Explain solar photovoltaic systems. What are the standards used in solar photovoltaic systems ?**

Answer

A. Solar Photovoltaic System :

1. It refers to a wide variety of solar electricity systems.
2. This system use solar array made of silicon to convert sunlight into electricity.
3. Components other than PV array are collectively known as balance of system (BOS) which includes storage batteries, an electronic charge controller and an inverter.
4. Storage batteries with charge regulators are provided for back-up power supply during periods of cloudy day and during nights.

5. Batteries are charged during the day and supply power to loads as shown in Fig. 1.12.1.

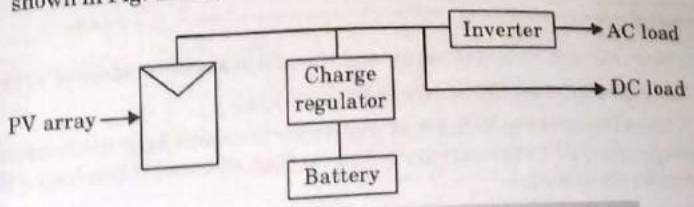


Fig. 1.12.1. Block diagram of solar photovoltaic system.

6. The capacity of a battery is expressed in ampere-hours and each cell of the lead-acid battery is of 2 volts.
7. Batteries are installed with a microprocessor based charge regulator to monitor the voltage and temperature.
8. It also regulates the input and the output current to eliminate overcharging and excessive discharge respectively.
9. An inverter is provided for converting DC power from battery or PV array to AC power.
10. It needs to have an automatic switch-off in case the output voltage from the array is too low or too high.
11. The inverter is also protected against over loading and short circuit.

B. Standards for Solar Photovoltaic Systems :

1. Photovoltaic standards have been established in India by the Bureau of Indian Standard (BIS).
2. For electrical safety and system reliability, PV devices need to conform to IS-12839 (1989) regulation regarding photovoltaic parts.
3. Measurement of current and voltage is covered by IS-12762 (1989) and IS-12763(1989) which deal with electrical characteristics of crystalline silicon cells.

C. Advantages of Photovoltaic Systems :

1. No operational cost.
2. Low maintenance.
3. These systems are durable.
4. More flexibility is available in solar photovoltaic systems.
5. These systems are eco-friendly.

D. Limitations of Photovoltaic Systems :

1. Low efficiency.
2. Weather dependent.
3. Installation cost is more.

Que 1.13. Write a short note on solar cell array.

Answer

1. Solar cells are strung in series and thus form a solar module or array.
2. They may be tracking arrays or fixed arrays.
3. A tracking array is defined as one which is always kept mechanically perpendicular to the sun-array line so that all times it intercepts the maximum isolation.
4. Such arrays must be physically movable by a suitable prime-mover and are considerably more complex than fixed arrays.
5. A fixed array is usually oriented east-west and tilted up at an angle approximately equal to the latitude of the site.
6. Fixed arrays are mechanically simpler than tracking arrays. Thus the array designs fall into two broad classes :

a. Flat-Plate Arrays :

1. Wherein solar cells are attached with a suitable adhesive to some kind of substrate structure usually semi-rigid to prevent cells being cracked.
2. This technology springs from the space–related photovoltaic technology, and many such arrays have been built in various power sizes.

b. Concentrating Arrays :

1. Wherein suitable optics, e.g., Fresnel lenses, parabolic mirrors, compound parabolic concentrators (CPC), and others, are combined with photovoltaic cells in array fashion.
2. This technology is relatively new to photovoltaic in terms of hardware development, and comparatively fewer such arrays have actually been built.

Que 1.14. With the aid of block diagrams explain :

i. Autonomous solar power plant, and

ii. Combined solar power plant. **UPTU 2012-13, Marks 10**

Answer

i. Autonomous Solar Power Plant :

1. This plant also known as grid independent or stand alone PV system for supplying the current having no connection with grid.
2. It is located at the load centre and dedicated to meet all the electrical loads of a village or community or a specific set of loads.
3. Energy storage is generally essential.
4. It is most relevant and successful in remote and rural areas having no access to grid supply.

5. Indicative capacity of such a system is 10 W – 100 kW.
6. The main components of a general stand-alone solar PV system are shown in Fig. 1.14.1.

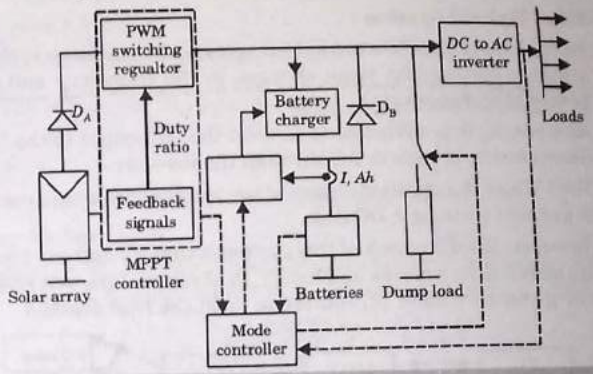


Fig. 1.14.1. A general stand-alone or autonomous solar PV system.

7. The MPPT senses the voltage and current outputs of the array and adjusts the operating point to extract maximum power under the given climatic conditions.
8. The output of the array after converting to AC is fed to loads.
9. The array output in excess of load requirement is used to charge the battery.
10. If excess power is still available after fully charging the battery, it may be shunted to dump heaters.
11. When the sun is not available, the battery supplies the load through an inverter.
12. The battery discharge diode D_B prevents the battery from being overcharged after the charger is opened.
13. The array diode D_A is to isolate the array from the battery to prevent battery discharge through array during nights.
14. A mode controller is a central controller for the entire system.
15. It collects the system signals and keeps track of charge or discharge state of the battery, matches the generated power and load and commands the charger and dump heater on-off operation.

ii. Combined Solar Power Plant or Hybrid PV System :

1. A hybrid PV system is essentially a system that employs at least one more source, other than the PV, to meet the electrical power demand of the loads.
2. The other sources that are generally used in conjunction with the PV source are diesel generators, wind generators, micro-turbines, fuel cells, etc.

3. The hybrid PV system can be classified depending on the type of source it uses, *e.g.*, PV-wind hybrid system, PV-diesel hybrid system and PV-fuel cell hybrid system.

a. PV-Wind Hybrid System :

1. In the case of the PV-wind hybrid system, the variation in the wind velocity results into large changes in the frequency and output power of the generator.
2. As a result, it is advisable to convert the AC output to the DC and then convert it back to AC through the inverter.
3. The PV and the rectified output of the wind generator are connected in parallel forming a DC link.
4. However, the drawback of this system is that PV and wind both are the unreliable, sources and hence, in absence of the sun and wind, a large battery bank is required to meet the load demand.

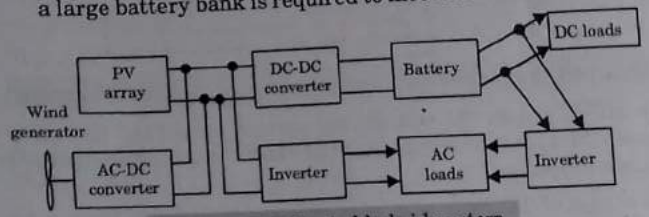


Fig. 1.14.2. PV-wind hybrid system.

Que 1.15. What are the advantages and limitations of solar energy system ?

Answer

A. Advantages :

1. Noiseless and cheap energy conversion system.
2. Low cost of maintenance.
3. Highly reliable.
4. Environment friendly.
5. Having long life.
6. Suitable for mobile loads such as cars, buses etc.
7. No fuel is required.
8. These systems are suitable for rural, remote and isolated areas.
9 Modularity in operation.
10. System modularity allows users to start with small system for single application and add on to their systems as their needs increase.

B. Limitations :

1. Higher initial cost.

2. Irregular supply of solar energy and do not generate power during cloudy season.
3. Require storage batteries for supply power during night.
4. Efficiency is low.
5. Large area required for plant.

Que 1.16. What are the applications of photovoltaic systems ?

Answer

1. The applications of photovoltaic systems are given below :

A. Solar Street Light :

1. It comprises of a compact fluorescent lamp, two 35 watt solar arrays and an 80 ampere-hour tubular cell battery as shown in Fig. 1.16.1.

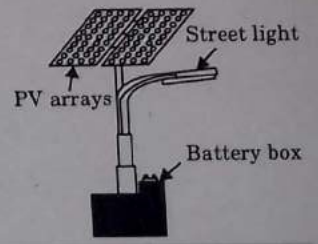


Fig. 1.16.1. Solar street light.

B. Home Lighting System :

1. These are the most popular solar PV units, typically designed to work with two light points and one TV point.
2. When necessary, a small DC fan can also be run from this system.

C. Water Pumping System :

1. It is another important application of photovoltaic systems.
2. These systems are mainly, employed in rural areas for agricultural applications, where power is not available easily and economically.

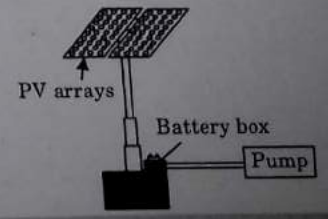


Fig. 1.16.2. Solar water pumping system.

3. Farmers use an 1800 watt PV array to operate a 2 hp DC motor pump set.

4. It can give water discharge of 140,000 litres per day from a depth upto 7 meters which is sufficient to irrigate 5-8 acres of land holding several crops.

D. Solar Vehicles :

1. Solar photovoltaic systems are also used in solar vehicles like solar cars, tractors etc. But solar vehicles are not used on commercial level until now.
2. Research and development is continuously trying to increase the efficiency of solar vehicles and to make it commercially workable.

☺☺☺

2 UNIT

Solar Thermal Energy

Part-1 ..... **(30M - 42M)**

- *Solar Radiation*

A. Concept Outline : Part-1 ..... 30M
B. Long and Medium Answer Type Questions 30M

Part-2 ..... **(42M - 55M)**

- *Flat Plate Collectors and their Materials, Applications and Performance*
- *Focusing of Collectors and their Materials, Applications and Performance*

A. Concept Outline : Part-2 ..... 43M
B. Long and Medium Answer Type Questions 43M

Part-3 ..... **(55M - 71M)**

- *Solar Thermal Power Plant*
- *Thermal Energy Storage for Solar Heating and Cooling*
- *Limitations*

A. Concept Outline : Part-3 ..... 56M
B. Long and Medium Answer Type Questions 56M

CONCEPT OUTLINE : PART-1

Solar Radiation : Solar radiation is the electromagnetic radiation emitted by the sun. This radiation can be converted into useful forms of energy, such as heat and electricity by the different types of technologies.

Solar Constant : The rate at which solar radiation strikes at the top of the atmosphere is called the solar constant I_{sc}. This is the average amount of energy received in unit time on a unit area perpendicular to the sun's direction at the mean distance of the earth from the sun.

Day Length : Day length (in hrs) is given by,

$$N = \frac{2}{15} \cos^{-1} [-\tan (\phi - \beta) \tan \delta]$$

Where, ϕ = Latitude angle,
β = Slope angle, and
δ = Declination angle.

Local Apparent Time (or Local Solar Time) :

LAT (LST) = Standard time + Equation of time correction ± 4 (standard time longitude – longitude of location)

Note : Negative sign is applicable for the eastern hemisphere.

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 2.1. **Write short note on "solar thermal energy".**

Answer

A. Solar Thermal Energy :

1. Solar energy is a clean, cheap and abundantly available renewable energ which has been used since ancient times.
2. Solar energy can be converted into electricity by using photovoltaic ce and solar collectors.
3. The sun is a sustainable source of providing solar energy in form radiations, visible light and infrared radiation.
4. This solar energy is captured naturally by different surfaces to produc thermal effect or to produce electricity by means of photovoltaic or da lighting of the buildings.

A. Spectral Distribution of Solar Radiation :

1. Solar radiation spectral distribution shows the distribution po of extraterrestrial and terrestrial radiation of different wavele
2. The maximum values of radiation are reaching in the ra 0.4 μm to 2.3 μm, with maximum value occurring at 0.48 μm.

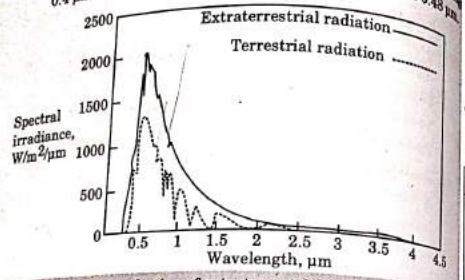


Fig. 2.2.1. Spectral distribution of extraterrestrial and terrestrial radia

B. Terms used in Solar Radiations :

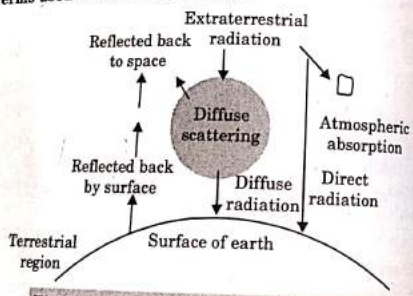


Fig. 2.2.2. Direct diffuse and total solar radiation.

i. **Beam Radiation (I_b) :** Solar radiation received on the ear surface without change in direction is known as beam or di radiation.

ii. **Diffuse Radiation (I_d) :** The radiation received on a terres surface (scattered by aerosols and dust) from all parts of the dome is known as diffuse radiation.

iii. **Total Radiation : (I_T) :** The sum of beam and diffuse radia (*i.e.*, $I_b + I_d$) intercepted at the earth's surface per unit are location is known as total radiation and it is also known as insolat

The radiations received by a collector surface are always global radiations.

iv. **Air Mass (m_a) :** It is the ratio of the path length of beam radiation through the atmosphere, to the length of path when sun is at over head or zenith.

Que 2.3. Describe the difference between the direct radiation and diffuse radiation. **UPTU 2013-14, Marks 05**

Answer

S.No.	Direct Radiation	Diffuse Radiation
1.	Solar radiation received on the earth's surface without change in direction is known as direct radiation.	The radiation received on a terrestrial surface (scattered by aerosols and dust) from all parts of the sky dome is known as diffuse radiation.
2.	It has a unique path.	It does not have a unique path.
3.	Direct solar radiation is generally most intense at any one spot on the surface of the earth at solar noon.	It does not happen in diffuse radiation.
4.	It has the least amount of the atmosphere to travel through.	It has the more amount of the atmosphere to travel through.

Que 2.4. What do you mean by solar constant ?

Answer

1. The solar constant is the energy received from the sun on a unit area perpendicular to sun's rays at the mean distance from the sun, outside the atmosphere.
2. The standard value of the solar constant based on experimental measurements is 1367 W/m^2 with an accuracy of ±1.5 %.
3. The value of solar constant remains constant throughout the year. However this value changes with location because earth to sun distance changes seasonally with time.
4. The extraterrestrial radiation observed on different days is known as apparent extraterrestrial solar irradiance and can be calculated on any day of the year using the following equation :

$$I_o = I_{sc}\left[1 + 0.033\cos\frac{360n}{365}\right]$$

Where, I_o = Apparent extraterrestrial solar irradiance (W/m^2),

n = Number of days of the year counting Jan 1 as the first day of the year, and

I_{sc} = 1367 W/m^2.

5. **Note :** According to above equation, the apparent solar irradiance will be maximum during December last or first week of January, as earth's centre is nearest to the sun during these days.

6. At sea level
   a. $m_a = 1$, when the sun is at directly over head or zenith,
   b. $m_a = 2$, when the angle subtended by zenith and line of sight of sun is 60°, and
   c. $m_a = 0$, just above the earth's atmosphere.

   At zenith angle θ_z, the air mass is calculated as,

$$\text{Air mass } (m_a) = \frac{AC}{AB} = \sec\theta_z = \frac{1}{\cos\theta_z}$$

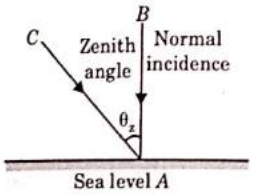


Fig. 2.4.1.

7. Zenith angle (θ_z) is the angle made by the sun rays with the normal the horizontal surface.
8. During winter, the sun is low and hence the air mass is higher and vi versa during summer.

A. Irradiance : The rate of incident energy per unit area of a surface known as irradiance.

B. Albedo :

1. The earth reflects back nearly 30 % of the total solar radiant energy the space by reflection from clouds, by scattering and by reflection at earth's surface. This is known as albedo of the earth's atmosphere syst

Que 2.5. Explain solar radiation geometry.

OR

With the help of neat diagram explain the zenith angle and altitude angle in respect of solar radiation analysis.

UPTU 2014-15, Marks 10

OR

Define the terms :

a. Altitude angle,
b. Incident angle,
c. Zenith angle,
d. Latitude angle, and
e. Hour angle.

Answer

1. The solar radiation comes from the sun on the earth's surface with arbitrary orientation and can be found out by knowing the beam radiation falling either on horizontal or perpendicular surface to sun's radiation.
2. The amount of incident beam flux on an inclined surface per unit time and per unit area is given as

$$I_N = I\cos\theta_i$$

   Where, I = Incident flux of beam radiation, and
   θ_i = Angle of incident of beam radiation.

3. The various angles which are useful for conversion of beam radiation on the arbitrary surface are :

a. Incident Angle (θ) :

1. It is defined as the angle between the incident beam radiation and the normal to a plane surface.

b. Latitude Angle (ϕ) :

1. The latitude of a place is the angle subtended by the radial line joining the place to the centre of the earth, with the projection of the line on the equatorial plane.
2. **Note :** The latitude is taken as positive for any location towards the northern hemisphere and negative towards the southern hemisphere *i.e.*, the latitude at equator is 0° while at north and south poles are +90° and – 90° respectively.

c. Declination Angle (δ) :

1. The declination is the angle made by the line joining the centres of the sun and the earth with its projection on the equatorial plane.
2. The declination angle varies from a maximum value of +23.5° on June 21 to a minimum of –23.5° on December 21.
3. The declination (in degrees), for any given day may be calculated from the approximate equation of "Cooper".

$$\delta = 23.45 \sin\left[\frac{360}{365}(284 + n)\right]$$

where, n is the number of days in the year.

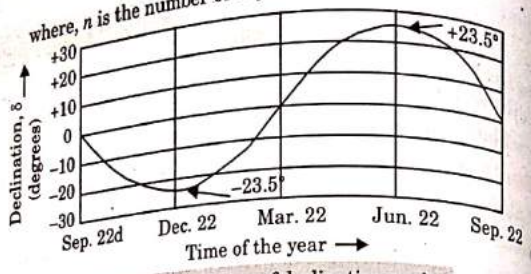


Fig. 2.5.1. Variation of declination angle.

d. Hour Angle (ω) :

1. It is the angle through which the earth must be rotated to bring its meridian of a point directly in line with the sun's ray.
2. In other words, it is the angular displacement of the sun, east or west of the local meridian, due to the rotation of the earth on its axis at an angle of 15° per hour.
3. The hour angle is zero at solar noon, negative in the morning and positive in the afternoon for the northern hemisphere (India) and vice-versa for southern hemisphere (Australia).
4. Mathematically hour angle can be expressed as

$$\omega = 15(\text{LST} - 12)$$

Where, LST = Local solar time.

e. Altitude Angle (α) :

1. It is a vertical angle between the projection of the sun's rays on the horizontal plane and the direction of the sun's rays.

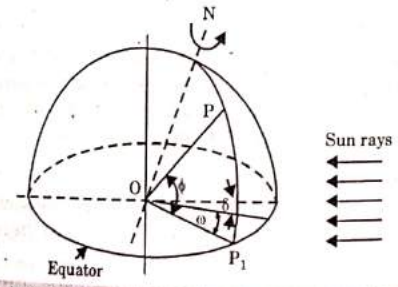


Fig. 2.5.2. Latitude ϕ, hour angle ω and sun's declination δ.

f. Zenith Angle (θ_z) :

1. It is the vertical angle between the sun's rays and line perpendicular to the horizontal plane through the point.

Mathematically :

$$\theta_z = \frac{\pi}{2} - \alpha$$

g. Surface Azimuth Angle (γ) :

1. It is the angle in the horizontal plane, between the line due south and the horizontal projection of the normal to the inclined plane surface.
2. By convention, the angle will be taken negative for northern hemisphere (India) and vice-versa for southern hemisphere (Australia).

h. Slope (β) :

1. It is the angle between the plane surface, under consideration, and with the horizontal.
2. It is taken to be positive for surface sloping towards south and negative for surfaces sloping towards north.

i. Solar Azimuth Angle (γ_s) :

1. It is the angle in a horizontal plane, between the line due south and the projection of beam radiation on the horizontal plane.
2. Thus it gives the direction of the shadow cast in the horizontal plane by a vertical rod.

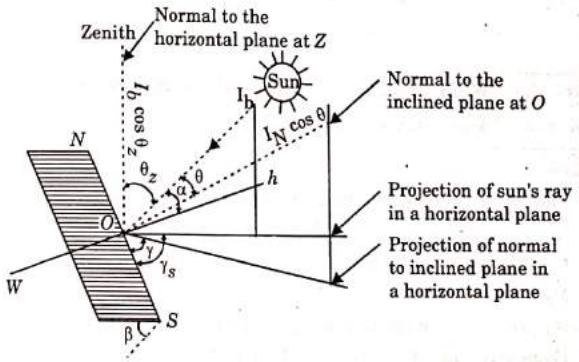


Fig. 2.5.3. Various sun-earth angle on tilted surface.

Que 2.6. **Write short note on :**

A. Day Length

B. Local Apparent Time (LAT).

Answer

A. Day Length :

1. The time of sunrise, sunset and the duration of the day length de upon the latitude of the location and the month in the year.
2. At sunrise and sunset, the sunlight is parallel to the ground surface a zenith angle of 90°.
3. The hour angle pertaining to sunrise or sunset (ω_s) is given below :

a. At solar noon, $\theta_z = 0$ and $\omega = \omega_s$

$$\cos \omega_s = -\tan\phi \tan\delta$$

b. On tilted surface,

$$\omega_s = \cos^{-1}[(-\tan(\phi - \beta)\tan\delta)]$$

4. The corresponding day length (in hours) is given by

$$N = \frac{2}{15}\cos^{-1}\left[-\tan(\phi-\beta)\tan\delta\right]$$

B. Local Apparent Time (LAT) :

1. The time used for calculating the hour angle ω is the local appare time.
2. It is given by

LAT = Standard time + Equation of tim correction + 4 (Standard time longitud – longitude of location)

Que 2.7. What are the devices used for measuring the sola radiations ? Explain each in brief.

Answer

1. There are three devices used for measuring the solar radiations :
   A. Pyranometer B. Pyrheliometer
   C. Sunshine recorder

A. Pyranometer :

1. It is a device used for measuring global or diffuse radiations.

a. Construction : It consists of following components :

i. Black Surface : This receives the beam as well as diffuse radiation which rises heat.

ii. Glass Dome : It prevents the loss of radiation received by the blac surface.

iii. Thermopile : It is a temperature sensor and consists of a number thermocouples connected in series to increase the sensitivity.

iv. Supporting Stand : It keeps the black surface in a proper position.

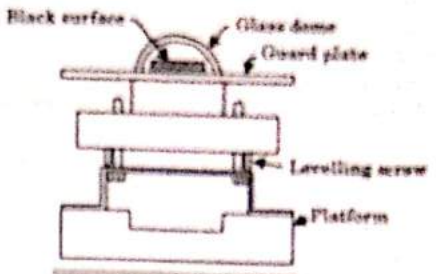


Fig. 2.7.1. Pyranometer.

b. Working :

1. The pyranometer is kept exposed to the sun and it starts receiving the radiations.
2. Due to the absorption of the radiation, the surface temperature starts rising and the increase in temperature of the absorbing surface is detected by the thermopile.
3. The thermopile generates a thermo-emf which is proportional to the radiations absorbed and this thermo-emf is calibrated in terms of the received radiations. This will measure the global radiations.

B. Pyrheliometer : It is a device used for measuring the beam or direct radiations.

a. Construction : It consists of following components :

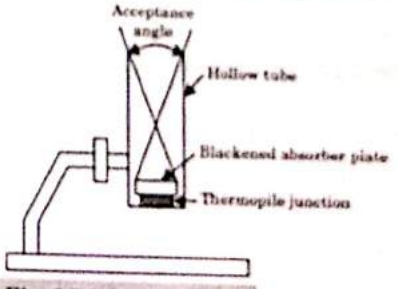


Fig. 2.7.2. Pyrheliometer.

i. Receiver : It is in the shape of a hollow tube with reflecting surface inside.

ii. Absorber Plate : It consists of a blackened surface and it is placed at the bottom of the tube.

iii. Thermopile : It is a sensing element of temperature consisting of a group of thermopiles.

b. Working :

1. The hollow receiver tube can be tilted about an axis perpendicular to its length.
2. Thus, the tube can be made to face the sun's radiation, thereby receiving only the beam radiation and no diffuse radiation can enter the tube.
3. When the radiation falls on the absorber plate, it absorbs the radiation and it gets heat up, and thereby temperature rises.
4. The rise in temperature is measured by measuring the thermo-emf of the thermopile.

C. Sunshine Recorder : It is a device used to measure the hours of bright sunshine in a day.

a. Construction :

1. It consists of a glass sphere installed in a section of spherical metal bowl, having grooves for holding a recorder card strip and the glass sphere for adjusting the focus of sun rays to a point on the card strip.

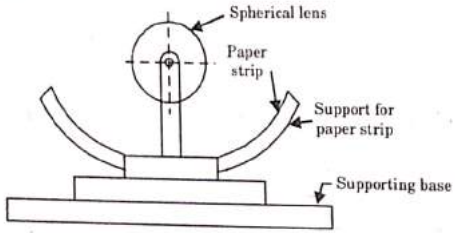


Fig. 2.7.3. Sunshine recorder.

b. Working :

1. Sun's beam is focused to a point by a spherical glass, which acts as a convex lens and graduated paper strip is placed at the focal point.
2. Due to the heating effect of the focused beam, a burn mark is produced on the paper and the graduation on the paper is done as per the hours of the day.

Que 2.8. Describe the various methods of solar radiation measurement. How can we measure all (direct, diffuse and global) radiations with the help of pyranometer ?

Answer

A. Various Methods of Solar Radiation Measurement : There are two common methods :

a. Solar Radiance :

1. The solar radiance is an instantaneous power density in units of kW/m^2

Que 2.9. **Find the angle subtended by beam radiation with the normal to a flat plate collector at 9 a.m. for the day on November 3, 2003. The collector is in Delhi (28° 35' N, 77° 12' E), inclined at an angle of 30° with the horizontal and is facing due south.**

Answer

1. **Given :** $\gamma = 0°$
   $n = 307$ for November 3, 2003
   $\beta = 30°$

2. Now, $$\delta = 23.45 \sin\left[\frac{360}{365}(284 + n)\right]$$
   $$= 23.45 \sin\left[\frac{360}{365}(284 + 307)\right]$$
   $$= 23.45 \sin 582.90° = -15.96°$$

3. At 9:00 a.m. (local apparent time) $\omega = 45°$.
   $$\cos\theta = \sin\delta \sin(\phi - \beta) + \cos\delta \cos\omega \cos(\phi - \beta)$$
   $$= \sin(-15.96°) \sin(28.58° - 30°) + \cos(-15.96°) \cos 45° \cos(28.58° - 30°)$$
   $$= 0.686$$
   $$\therefore \quad \theta = 46.68°$$

Que 2.10. **i. Calculate the angle of declination for 5th May of a leap year.**
ii. Calculate the hour angle at the time 8.15 p.m.

Answer

i. Angle of declination for 5th may of a leap year,
Angle of declination,
$$\delta = 23.45 \sin\left(\frac{(284 + n) \times 360}{365}\right)$$
$n = 125$
$$\delta = 23.45 \sin\left(\frac{(284 + 125) \times 360}{365}\right)$$
$\delta = 16.11°$

ii. Hour angle, $\omega = 15\,(h - 12)$
$h = 20.25$ hr
$\omega = 15(20.25 - 12) = 123.75°$

PART-2

Flat Plate Collectors and their Materials, Applications and Performance, Focusing of Collectors and their Materials, Applications and Performance.

CONCEPT OUTLINE : PART-2

Solar Collectors : A solar collector absorbs the incident solar radiation and convert it to useful heat which is used for heating a collector fluid such as water, oil or air. The surface of solar collector is designed for high absorption and low emission.

Classification : Solar collectors can be classified as :
a. Non-concentrating or flat plate type collectors.
b. Concentrating or focusing collectors.

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 2.11. **What are solar collector ? How solar collectors are classified ?**

Answer

1. Solar collectors are used to collect the solar energy and convert this energy into the thermal energy by absorbing them.
2. This thermal energy is further used for heating a collector fluid such as water, oil or air.
3. Solar collector surface is designed for high absorption and low emission.
4. Solar collectors are classified in two types :
   a. Non-Concentrating Collector :
   1. It is also known as flat plate solar collector.
   2. In these collectors, the area of collector to grasp the solar radiation is equal to the absorber plate and has concentration ratio of 1.
   b. Concentrating Collector :
   1. It is also known as focusing type solar collector.
   2. In these collectors, the area of the collector is kept less than the aperture through which the radiation passes, to concentrate the solar flux and has high concentration ratio.

Que 2.12. **Explain the principle of conversion of solar energy into heat. Explain a flat plate solar collector.**

UPTU 2013-14, Marks 10

OR

What are the main components of a flat plate solar collector ? Explain.

Answer

A. Principle :

1. When solar radiation from the sun comes in the form of light (a sh wave radiation) to the earth, visible sunlight is absorbed on the grou and transformed into heat energy ; the material becomes warm a stores the heat, conducts it to surrounding materials (air, water oth solids or liquids) or reradiates it to other material of lower temperatu

b. Flat Plate Collector :

1. Flat plate collector is simplest in design and it is most important part any solar thermal energy system.
2. In this collector both direct and diffuse radiations are absorbed a converted into useful heat.

a. Components of Flat Plate Collector :

i. Absorber plate,
ii. Transparent covers,
iii. Insulation, and
iv. Box.

i. Absorber Plate :

1. Absorber plate is used to grasp and absorb solar radiation.
2. The plate is usually metallic (copper, aluminum or steel), sometim plastics have been used in some low temperature applications.

ii. Transparent Covers :

1. These are one or more sheets made of glass for trapping the he received by the absorber plate.
2. It helps in reducing the convective and radiative heat losses.

iii. Insulation : It minimizes the heat losses by conduction.

iv. Box : It contains the above components and keep them into desir position.

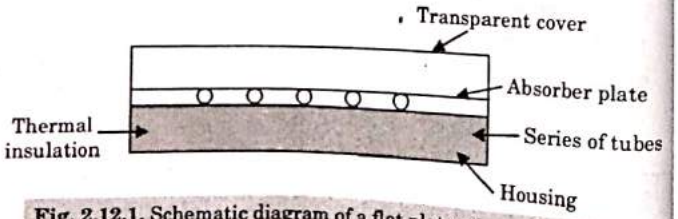


Fig. 2.12.1. Schematic diagram of a flat plate solar collector.

C. Advantages of Flat Plate Collector :

1. It absorbs both direct and diffuse radiations.
2. There is no need of tracking.

3. It has low cost and requires less maintenance.

D. Disadvantages of Flat Plate Collector :

1. Low temperature is achieved.
2. There is a large heat loss by conduction due to large area.
3. These are heavy in weight.

E. Applications of Flat Plate Collector :

1. It is used in solar water heating.
2. It is used in space heating and cooling.
3. It is used in low temperature power generation.

Que 2.13. Describe the construction of solar flat plate collector. How is its performance evaluated ? **UPTU 2012-13, Marks 10**

OR

What do you understand by performance analysis of flat plate collector ?

Answer

A. Construction of Solar Flat Plate Collector : Refer Q. 2.12, Page 43M, Unit-2.

B. Performance Analysis of Flat Plate Collector :

The performance of solar collector depends on the following factors :

a. Fin Efficiency Factor (F_e) : It is defined as the ratio of actual rate of heat transferred to the heat that would be transferred, if entire fins (plate area) are at base temperature.

Mathematically,

$$F_e = \frac{Q_{actual}}{A_c[\alpha_o \tau_o I_t - U_L(T_p - T_a)]}$$

Where, Q_{actual} = Actual rate of heat transferred to the tube base,

A_c = Collector area,

I_t = Incident total radiations,

U_L = Overall heat loss coefficient,

T_p = Plate temperature,

T_a = Ambient temperature,

α_o = Absorptivity, and

τ_o = Transmitivity.

b. Collector Efficiency Factor (F_c) : It is defined as the ratio of useful heat removed by flowing fluid in the tubes to the rate of heat transferred to the fluid, if the fin is at local fluid temperature.

Mathematically,

$$F_c = \frac{Q_u}{A_c[\alpha_o \tau_o I_t - U_L(T_f - T_a)]}$$

Where, Q_u = Useful heat removed by flowing fluid in t tubes, and

T_f = Local fluid temperature.

c. Collector Heat Removal Factor (F_H) : It is defined as the ratio actual useful energy gain by fluid to the rate of heat transferred to t fluid, if the fin is at inlet fluid temperature.

Mathematically,

$$F_H = \frac{Q_u}{A_c[\alpha_o \tau_o I_t - U_L(T_{fi} - T_a)]}$$

or,
$$F_H = \frac{mC_f(T_{fo} - T_{fi})}{A_c[\alpha_o \tau_o I_t - U_L(T_{fi} - T_a)]}$$

Where, m = Mass flow rate of fluid per unit area of collecto

C_f = Specific heat of fluid,

T_{fo} = Outlet fluid temperature, and

T_{fi} = Inlet fluid temperature.

d. Collector Efficiency (η_c) : It is defined as the ratio of useful energ absorbed by collector to the incident solar energy over it.

Mathematically,

$$\eta_c = \frac{Q_u}{A_c I_t}$$

or
$$\eta_c = \frac{F_R A_c[\alpha_o \tau_o I_t - U_L(T_{fi} - T_a)]}{A_c I_t}$$

$$[\because Q_u = F_R A_c(\alpha_o \tau_o I_t - U_L(T_{fi} - T_a)]$$

or
$$\eta_c = F_R \alpha_o \tau_o - \frac{F_R U_L(T_{fi} - T_a)}{I_t}$$

or $\eta_c = mx + c$

Where, $m = -F_R U_L$ (It is a linear equation (Effective heat loss coefficient

$$x = \frac{(T_{fi} - T_a)}{I_t}$$

and, $c = F_R \alpha_o \tau_o$ (Effective optical efficiency

Que 2.14. Write a short note on materials used for flat plate collectors.

Answer

1. The properties of the materials used for collectors can be classified as :
   a. Thermophysical properties such as thermal conductivity, heat capacity etc.
   b. Physical properties like density, tensile strength, melting point etc., and environmental properties like moisture penetration, corrosion resistance and degradation due to pollutants in atmosphere.
2. The material for absorber plate should have high thermal conductivity, adequate tensile strength and good corrosion resistance.
3. The most common material used for absorber plate is Copper because of high conductivity and resistance to corrosion.
4. Other materials which are used for absorber plate are Aluminium, Iron, Brass, Silver, Tin and Zinc.
5. The material for insulation should have low thermal conductivity, should be stable at high temperature.
6. Some commonly used materials are crown white wool, glass wool, calcium silicate, cellular foam etc.
7. For cover plate, tempered glass is most common material. Transparent plastic materials such as acrylic polycarbonate plastic, polyvinylfluoride are used for cover plate.

Que 2.15. What are the factors which affect the performance of flat plate collector ?

Answer

1. The different factors which affect the performance of flat plate collector are :

a. Incident Solar Radiation :
   1. The efficiency of collector is directly related with solar radiation falling on it and increases with rise in temperature.

b. Number of Cover Plate :
   1. Increase in number of cover plate reduces the internal convective heat losses but also prevents the transmission of radiation inside the collector.
   2. Therefore, the increase in cover plates will reduce the heat absorbed by the absorber.

c. Spacing between Absorber Plates and Glass Cover :
   1. The more space between the absorber and the cover plate, the less is the internal heat losses.

d. Collector Tilt :
   1. To achieve better performance, flat plate collector should be tilted at angle of latitude of the location.

2. The collector is placed with south facing at northern hem receive maximum radiation throughout the day.

e. **Selective Surface :**

1. It should be able to withstand high temperatures.
2. It should not oxidise.
3. It should be corrosion resistant.

f. **Fluid Inlet Temperature :**

1. On increasing the inlet temperature of the fluid there is in operating temperature of the collector and this lead to in efficiency.

g. **Dust on Cover Plate :**

1. The efficiency of collector decreases as dust particles incre the cover plate.
2. Frequent cleaning is required to get the maximum effic collector.

Que 2.16. **Discuss the principle of a concentrating solar col How it differs with flat plate collector ? How collector coati be used to improve the performance of collector with refere the flat plate collector ? What is the concentrating ratio for fo collector ?** **UPTU 2014-15, Mark**

OR

Explain the concentrating solar collector. Also, discuss its w

Answer

A. Concentrating Solar Collector :

1. Concentrating solar collector is a device to collect solar energy w intensity of solar radiation on the absorbing surface by the reflector or refractor.

OR

A concentrating solar collector is a modified form of flat-plate col by introducing a reflecting or refracting surface between the radiation and absorber.

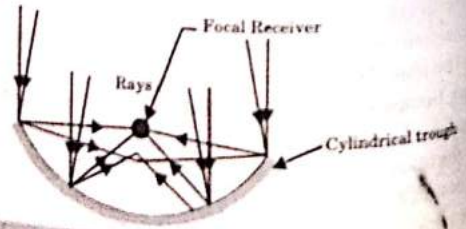


Fig. 2.16.1. Concentrating type of collector.

B. Principle :

1. Concentrating solar collector uses reflective surface to concentrate sunlight to a small area, where it absorbed and converted to heat.

C. Working of Concentrating Solar Collector :

1. This collector system comprises of a concentrator and an absorber.
2. In these collectors radiation from sun falls on a relatively large area which is focused through concentrator on to an absorber of considerably smaller area.
3. As a result of energy concentration, fluid can be heated up to a temperature of 500 °C or more.
4. These systems have high collector efficiency, since the losses are much less as compared to non-concentrating type of collectors.

D. Comparison between Flat and Focusing Collectors :

1. Owing to the small area of absorber per unit of solar energy collecting area, selective surface treatment and vacuum insulation (to reduce heat losses and improve collector efficiency) are economically feasible.
2. Since higher temperatures can be achieved, the focusing collector can be used for power generation.
3. Little or no anti-freeze is required to protect the absorber in a concentrator system where the entire solar collection surface requires anti-freeze protection in a flat-plate collector.
4. Costly orienting systems have to be used to track the sun.
5. Non-uniform flux on the absorber whereas flux in flat plate collector is uniform.

E. Use of Collector Coating to Improve the Performance of Collector :

1. Most solar collectors employ a transparent cover plate often made of glass. These materials reflect around 8 % of the incident solar radiation, which leads to the reduction in the collector heat output.
2. The use of an antireflection coating could therefore improve the performance of such system by increasing the transmitted energy through the glass cover.
3. Recently, a silica low-reflection coating via a dip-coating process has been developed.
4. The refractive index of the thin film is well controlled.
5. The exact value of the film refractive index that leads to a minimum of reflection on the surface of the glass cover can be achieved.
6. A comparison has been made between an uncoated flat-plate solar collector glass cover and one with a porous sol-gel anti-reflection coating. Using the porous sol-gel coating with the index of refraction of $n = 1.23$ on the glass cover of the solar collector increases the useful energy by a factor of approximately 1.05.

F. Concentration Ratio (C) : It is defined as the ratio of the effective aperture ratio to the absorber tube area.

Mathematically,

$$C = \frac{\text{Effective aperture ratio}}{\text{Absorber tube area}}$$

$$= \frac{W - D_o}{\pi D_o}$$

Where, W = Aperture, and

D_o = Outer diameter of absorber tube.

Que 2.17. **What do you understand by performance analysis of concentrator collector ?**

Answer

A. Performance Analysis : The performance of concentrator collector depends on the following factors :

a. Concentration Ratio (C) : It is defined as the ratio of the effective aperture ratio to the absorber tube area.

Mathematically,

$$C = \frac{\text{Effective aperture ratio}}{\text{Absorber tube area}}$$

$$= \frac{W - D_o}{\pi D_o}$$

Where, W = Aperture, and

D_o = Outer diameter of absorber tube.

b. Intercept Factor (γ) : It is defined as the ratio of radiation intercepted by absorber tube to the total reflected radiation.

Mathematically,

$$\gamma = \frac{\text{Radiation intercepted by absorber tube}}{\text{Total reflected radiation}}$$

c. Collector Efficiency Factor (F_c) : Collector efficiency factor is given by the relation :

$$F_c = \frac{1}{U_l\left[\frac{1}{U_l} + \frac{D_o}{D_i h_f}\right]}$$

Where, U_l = Overall heat loss coefficient,

D_o and D_i = Outer and inner diameter, and

h_f = Heat transfer coefficient of the tube.

d. Instantaneous Collector Efficiency (η_i) : Instantaneous collector efficiency is given by the relation :

$$\eta_i = \frac{q_u}{(I_b r_b + I_d r_d)WL}$$

Where, q_u = Useful heat gain,

$I_b r_b$ = Beam radiation normally incident on aperture,

$I_d r_d$ = Diffuse radiation, and

L = Length of concentrator.

Que 2.18. **Enumerate the different types of concentrating collector.**

Answer

1. The different types of concentrating collector are as follows :

a. Parabolic Trough Collector :

i. Principle : The principle of parabolic trough collector is, when the solar radiations falls on the area of parabolic reflector are concentrated at the focus of parabola.

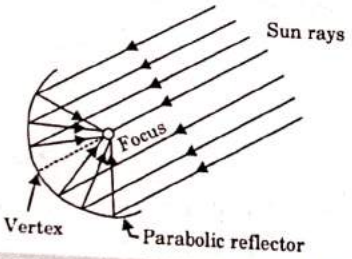


Fig. 2.18.1. Cross section of parabolic trough collector.

ii. Working :

1. In the parabolic trough collector mostly cylindrical parabolic concentrators are used in which the absorber is placed along the focus axis where collector pipe is used as an absorber with a selective coating.
2. The solar radiation coming from particular direction is collected over the area of collector and then focused to the collector pipe which is placed along the focus line to heat up the fluid.
3. The orientation of the parabolic trough collector is kept in the east-west or north-south directions.

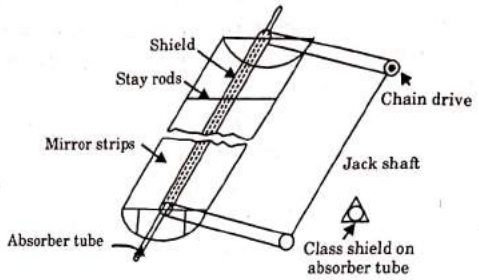


Fig. 2.18.2. A typical cylindrical parabolic system.

b. Mirror-Strip Reflector :

1. It has a number of planes or slightly curved or concave mirror strips which are mounted on a base.
2. These individual mirrors are placed at such angles that the reflected solar radiations fall on the same focal line where the absorber pipe is placed.
3. In this system, collector pipe is rotated so that the reflected rays on the absorber remain focused with respect to changes in sun's elevation.

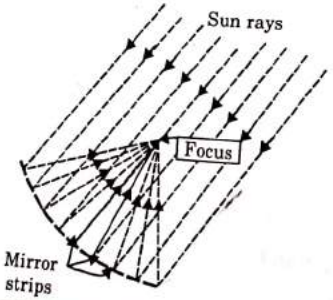


Fig. 2.18.3. Mirror-strip solar collector.

c. *Fresnel Lens Collector :*

1. In this collector, a Fresnel lens is used in which linear grooves are present on one side and flat surface on the other side.
2. The solar radiations which fall normal to the lens are refracted by the lens and are focused on the absorber (tube) as shown in Fig. 2.18.4.

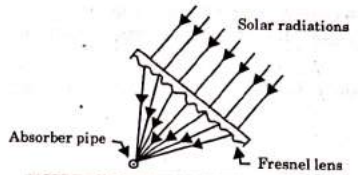


Fig. 2.18.4. Fresnel lens collector.

d. Compound Parabolic Concentrator (CPC) :

1. It is also known as Winston collector.
2. It is a trough like arrangement of two facing parabolic mirrors which are attached to an absorber.
3. In this system, solar radiations from all directions are reflected towards the absorber kept at the bottom, which collects both direct and diffused solar radiations to heat up the fluid.

i. Advantages :

1. It has high concentration ratio.
2. There is no need of tracking.
3. The efficiency for accepting diffuse radiation is high.

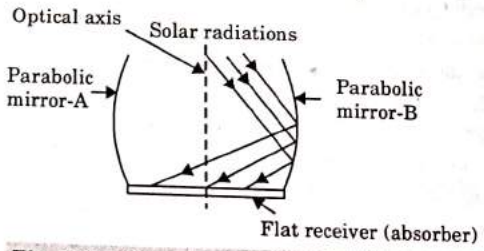


Fig. 2.18.5. Compound parabolic concentrator (CPC).

Que 2.19. Write a short note on materials used for concentrators.

Answer

1. The reflector of a concentrator should have high reflectivity therefore mirror glass or front surface mirrors can be used.
2. Glass is the most durable with low iron content and is used as a transmitting material. Now a days plastics are also in use.
3. Acrylic is found to be a good material for Fresnel lenses. Polymethyl methacrylate is generally used.

4. Glass and transparent plastic films are generally used as cover materia for receivers. Glass should have low iron content to reduce absorption
5. Coatings are required to have strong solar absorptivity, weathe resistance, stability at high temperature. Black paints are good. Blac chrome is also suitable. It can be electroplated on steel, copper, aluminium etc.
6. Other metal oxide coatings are black copper oxides, black nickel etc Insulation is required to reduce heat losses. Fiber glass with and without binder, urethane foams and mineral fibre blankets are commonly used for insulation.

Que 2.20. **Write advantages and disadvantages of concentrating collector over flat plate solar collectors and applications of concentrating collectors.**

Answer

A. Advantages of Concentrating Collector :

1. It gives high concentration ratio.
2. High fluid temperature can be achieved (upto 500 °C).
3. Thermal heat loss is less.
4. Efficiency of this system increases at high temperature.
5. In expensive process.

B. Disadvantages of Concentrating Collector :

1. These collectors are best suited for places having more number of clear days in a year.
2. It has non-uniform flux on absorber.
3. It needs costly tracking device.
4. It has high initial cost.
5. It needs maintenance in order to retain the quality of reflecting surface against dirt and oxidation.

C. Applications :

1. They are used for which need high amount of heat such as power generation.
2. They used in solar power plant.
3. They used to collected large solar energy which is used to convert water into steam.

Que 2.21. **Distinguish between global radiation and diffuse radiation. Describe the procedure for evaluating the performance of a solar collector.**

UPTU 2011-12, Marks 10

CONCEPT OUTLINE : PART-3

Solar Thermal Power Plant : Solar thermal power generation involves the collection of solar heat which is utilized to increase the temperature of a fluid in a turbine operating on a cycle such as Rankine or Brayton.

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 2.23. Explain the different types of solar thermal power plants.

Answer

A. Solar Thermal Power Plant :

1. Solar thermal power generation involves the collection of solar heat which is utilized to increase the temperature of a fluid in a turbine operating on a cycle such as Rankine or Brayton.
2. Solar thermal power plants can be classified as low, medium and high temperature cycles.
3. Low temperature cycles operate at about 100 °C, medium temperature cycles up to 400 °C, while high temperature cycles work above 500 °C.

a. Low Temperature Solar Power Plant :

1. A low temperature solar power plant uses flat-plate collector arrays shown in Fig. 2.23.1.
2. Hot (above 90 °C) water is collected in an air insulated tank. It flows through a heat exchanger, through which the working fluid of the energy conversion cycle is also circulated.
3. The working fluid is either methyl chloride or butane having a low boiling temperature up to 90 °C.
4. Vapours so formed operate a regular Rankine cycle by flowing through a turbine, a condenser and a liquid pump.
5. As the temperature difference between the turbine outlet and the condensed liquid flowing out is small, *i.e.*, about 50 °C, the overall efficiency of the generating system is about 2 % (8 % pumped cycle efficiency × 25 % collector system efficiency).
6. Finally, the organic fluid is pumped back to the evaporator for repeating the whole cycle.

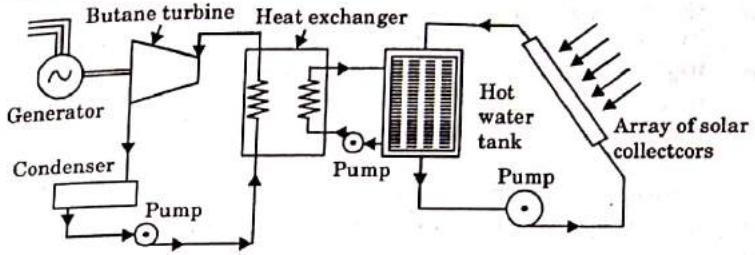


Fig. 2.23.1. Low temperature solar power plant.

7. Such plants up to 150 kW capacities are operative in Israel for the last 25 years.

b. Medium Temperature Solar Power Plant :

1. Solar thermal power plants operating on medium temperatures up to 400 °C use the line focusing parabolic collector for heating synthetic oil flowing in the absorber tube as shown in Fig. 2.23.2. A schematic diagram of a typical plant is shown in Fig. 2.23.2.

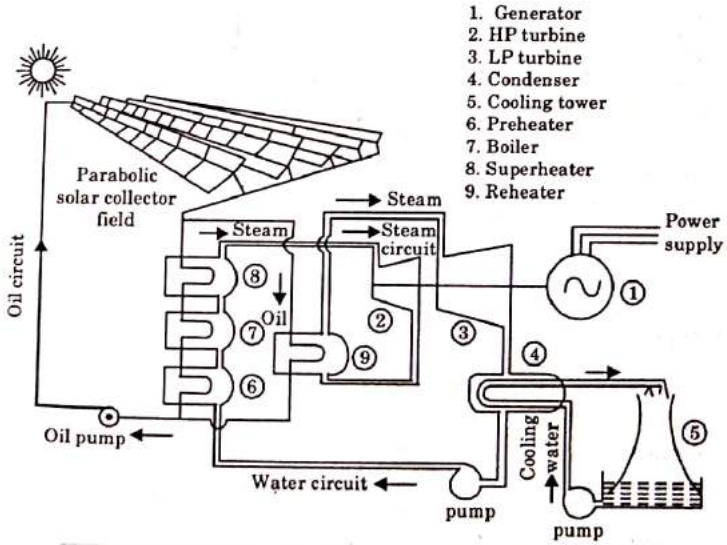


Fig. 2.23.2. Medium temperature solar power plant.

2. A suitable sun-tracking arrangement is made to ensure that maximum quantity of solar radiation is focused on the absorber pipeline.
3. Preheater and superheater are used to increase the inlet steam temperature for the high pressure (HP) turbine.
4. Reheaters are used to raise the steam temperature for low pressure (LP) turbine.

5. The system generates superheated high pressure steam to operate a Rankine cycle with maximum efficiency.

c. High Temperature Solar Thermal Power Generator :

1. For efficient conversion of solar heat into electrical energy, the working fluid needs to be delivered into turbine at a high temperature.
2. There are two possible systems-the 'paraboloidal dish' and the 'central receiver' to achieve high temperatures.

d. Central Receiver Power Plants :

1. In these power plants, solar radiations are reflected from arrays of mirrors (called heliostats) installed in circular arcs around provided with a tracking tower.
2. Reflected radiations concentrate on to the receiver.
3. The array is provided with a tracking control system that focuses beam radiation towards the receiver as shown in Fig. 2.23.3.

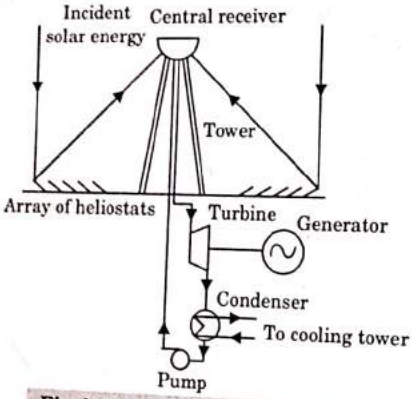


Fig. 2.23.3. Central receiver power plant.

4. Water is converted into steam in the receiver itself that operates a turbine coupled with a generator.
5. Alternatively, the receiver may be utilized to heat a molten salt and this fluid is allowed to flow through a heat exchanger where steam is generated to operate the power cycle.
6. The 'central receiver' is an important part of the collection equipment.
7. Typically, two receiver designs are in use external type and cavity type. The external receiver is cylindrical in shape; the solar flux reaches the outer surface and heat is absorbed by the receiver fluid flowing through the tubes on the inner surface.
8. In a 'cavity receiver', the solar flux enters through several apertures, where the radiant energy is transferred to the receiver fluid.

Que 2.24. Explain the principle of solar pond.

OR

What is meant by solar pond ? Explain.

Answer

A. Solar Pond :

1. Solar pond is a natural or artificial body of water for collecting and absorbing solar radiation energy and storing it as heat.

B. Principle :

1. Solar pond works on the principle of solar energy collection and sensible heat storage.

C. Construction :

1. A simplest form of a solar pond is a shallow water body with a absorber (black plastic) at bottom and a transparent cover at the top which is provided with insulation below the bottom of pond to reduce heat losses.

D. Working :

1. The solar radiations fall on the transparent cover are absorbed by the liner (cover reduces the heat losses by radiation and convection).
2. The absorbed solar radiation heated the bottom layer of water and moves up because of density gradient and it develops the convection currents.
3. Due to large water body, the temperature rises by few degrees.
4. This hot water can only be used for space heating.

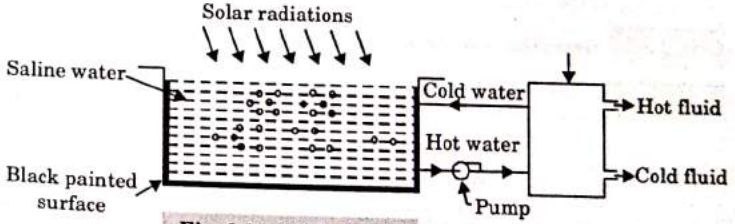


Fig. 2.24.1. Solar pond.

Que 2.25. Write short note on "salt gradient solar pond".

Answer

A. Principle : Refer Q. 2.24, Page 59M, Unit-2

B. Construction :

1. It consists of a salt gradient solar pond (artificially built large shallow structure about 1 to 2 m deep) which is provided with thick blackened plastic liner made by polyethylene.

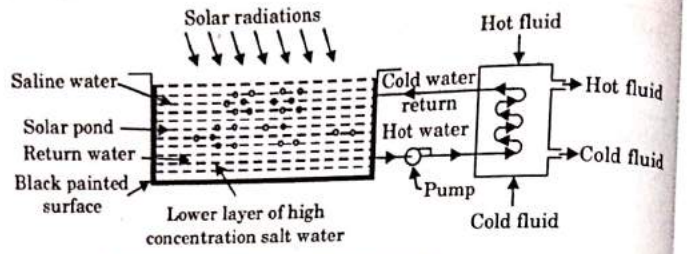


Fig. 2.25.1. Salt gradient solar pond.

C. Working :

1. In this process, water is made saline by dissolving salts (like magnesium chloride and sodium chloride) in water and maintaining a concentration gradient.
2. The addition of salt makes the water at the bottom denser compared to the fresh water at the top layer.
3. The solar radiations are transmitted through the upper layer to the bottom layer and these radiations are absorbed by the liner.
4. The higher density bottom layer of water gets heated up rapidly and due to the higher density, the heat can not be transmitted by bottom layer to upper layer by convection.
5. The hot water is drawn by the pump which is transferred to the working fluid in the heat exchanger.
6. After transfer of heat, the hot water becomes cold and it is returned at the top of the pond.

Que 2.26. Describe a solar water heating system.

Answer

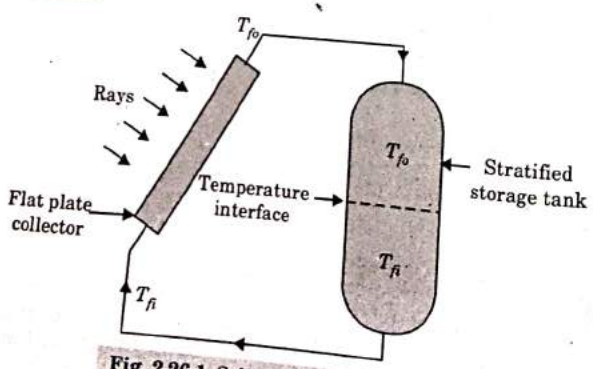


Fig. 2.26.1. Solar water heater.

A. Components : The main components of this system are :

a. Flat plate collector,
b. Storage tank, and
c. Support structure.

B. Working :

1. A flat plate collector collects the sun's radiations due to which water is heated, the hot water rises up and flows naturally to the storage tank due to decrease in its density.
2. The colder water from the bottom of storage tank having higher density replaces the hot water.
3. Thus, the density difference of hot and cold water provides a driving force to set up the natural convection for circulation of water through the storage tank and the solar collector.
4. The pump is not required to circulate the water in the system.
5. The hot water for use is withdrawn from the top of storage tank.

Que 2.27. What do you understand by solar pumping ? Describe.

Answer

A. Solar Pumping : Solar water pump is used to pump the water from lower level to higher level with the help of solar energy.

B. Principle : Solar pumps work with the help of solar cell (or solar photovoltaic panels), which convert solar energy into electrical energy.

C. Construction : Solar pump consists of solar array, circuit, pump and water storage system.

D. Working :

1. In solar pumping systems, solar array collects the solar radiations and convert into electrical energy.
2. This electrical energy charge the battery and this is further utilized to run the pump, to raise the water from lower level to higher level.

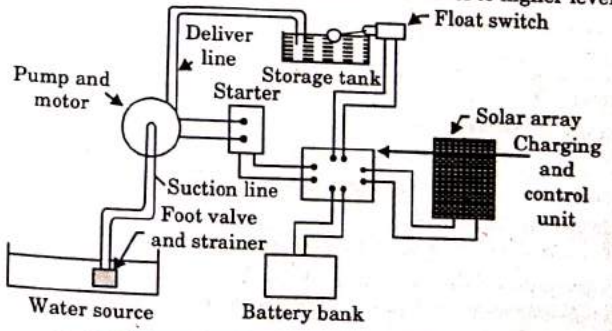


Fig. 2.27.1. Solar pumping system.

Que 2.28. **Write a short note on solar cooking.**

Answer

A. Solar Cooking :

1. Solar cooking is done by the help of solar cooker.
2. A solar cooker is a device which uses sunlight as its energy source and these sun's rays are absorbed by a blackened metal tray which kept inside the solar box. Thus, the temperature inside the box starts rising.
3. The cooking pots, which are also blackened, are placed inside with food material, to get heat energy.
4. Food will be cooked in a certain period of time depending upon the actual temperature attained inside.
5. Solar cookers are commonly able to reach at cooking temperatures of 90-150 °C and some can even reach to 230 °C.

B. Advantages :

1. The solar cooker's fuel is freely available from the sun.
2. No attention is needed during cooking as in other devices.
3. Nutrition value is maintained.
4. Maintenance cost is low.
5. It does not create pollution.

C. Disadvantages :

1. The food can not be cooked in the night or during cloudy days.
2. It takes more time.
3. Initial cost is more.

Que 2.29. **What do you understand by "solar distillation" ?**

OR

What is a solar still ? Draw its diagram and explain the working in detail.

Answer

A. Solar Distillation (Solar Still) :

1. The process use to convert saline water into pure water by using solar energy is called solar distillation and the device used is called solar still.

B. Construction :

1. It is a shallow basin having blackened surface called basin liner.
2. Filler supplied the saline water to the basin and a overflow pipe allows the excess water to flow out from the basin.
3. The top of the basin is covered with a sloping air tight transparent cover that encloses the space above the basin.

a. Thermal Energy Storage :

1. It is the storage of energy by heating, melting or vaporization of material and the energy becomes available as heat.
2. Thermal energy storage are of two types :

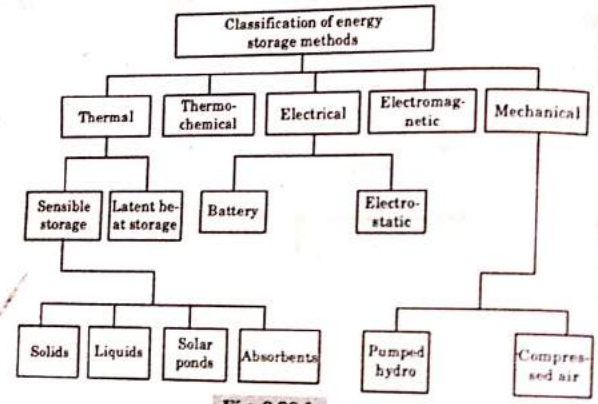


Fig. 2.30.1.

i. Sensible Heat Storage :

1. The energy stored in this system is due to rise in temperature of the storage medium (solid or liquid).
2. When the phase does not change on heating solid or liquid, then this type of storage is called sensible heat storage.
3. The sensible energy (E) is given by the relation :

$$E = m\int_{T_1}^{T_2} c_p.dT$$

Where, m = Mass,

c_p = Specific heat at constant pressure,

T_1 = Initial temperature, and

T_2 = Final temperature.

ii. Latent Heat Storage :

1. The energy stored in this system is in the form of latent heat caused by phase change during heating either from solid to liquid or liquid to vapour.

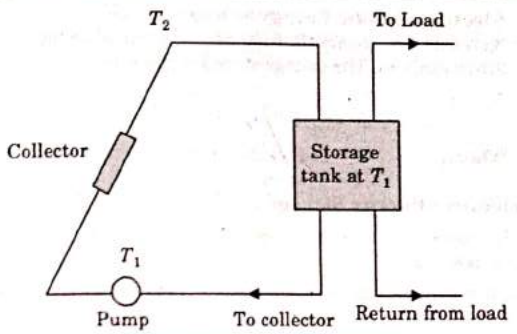


Fig. 2.30.2. Latent heat storage.

b. Thermo-Chemical Energy Storage :

1. In this process, the heat of a chemical reaction is used to store thermal energy.
2. This system is suitable for medium and high temperature applications.

For example : $A + B \xrightarrow{\text{Solar heat absorbed}} C + D$

c. Electric Storage :

1. In this process, the capacitor stores large amount of electrical energy for long periods.
2. The total energy stored is given by

$$\text{T.E.} = \frac{1}{2} V\varepsilon E^2$$

Where, V = Volume of the dielectric,

ε = Dielectric constant, and

E = Electric field strength.

3. These are of two types :
   - **i. Battery Storage :** A rechargeable storage battery (called secondary battery) receives electrical energy as direct current which is stored in the form of chemical energy by a reversible electro-chemical reaction.
   - **ii. Electrostatic Energy Storage :** It is the energy stored in the large capacity capacitors. The total energy stored is given by :

$$H = \frac{1}{2} \varepsilon.V.E^2$$

Where, ε = Dielectric constant,

V = Volume of the dielectric, and

E = Electric field strength.

iii. **Electromagnetic Energy Storage :** In this process, the energy stored in the magnetic field of a superconducting coil, carrying direct current. The energy stored is given by :

$$E = \frac{1}{2} LI^2$$

Where, L = Inductance, and
I = Current.

d. Mechanical Energy Storage :

1. In this process, the energy can be stored in the form of kinetic energy potential energy.
2. So, in this process the storage of solar energy firstly converts into the two forms of energy before utilization.
3. These are of two types :

i. Pumped Hydro Storage :

1. Pumped hydro storage system consists of two reservoirs *i.e.*, upper and lower reservoir.
2. A pump-turbine combination is installed between these reservoirs which can work as a pump or turbine and the energy to be stored is developed by a solar engine which is further used to drive the pump to raise the water from lower reservoir to upper reservoir.
3. Therefore, the energy stored in upper reservoir is potential energy
4. When water flows down from upper reservoir to the lower reservoir the pump and turbine combination acts as a turbine to convert potential energy into the mechanical energy.
5. This mechanical energy can be further converted into electrical energy by a generator which is coupled to the turbine.

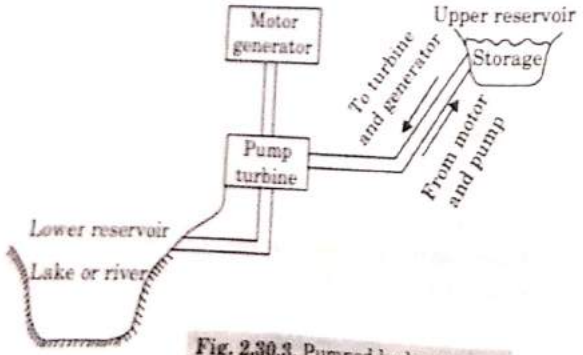


Fig. 2.30.3. Pumped hydro storage.

b. Compressed Air Storage :

i. Compressed air energy storage has similar principles as pumped storage system.

OR

Explain the thermal energy storage for solar cooling.

Answer

1. Solar energy can be used for cooling the buildings and preserving f by refrigeration.
2. The cycle used for cooling with utilization of solar energy is vap absorption cycle.
3. The performance of vapour absorption system depends upon working fluids pair *i.e.*, refrigerant and absorbent.
4. On the basis of this, the absorption systems are classified as :
   a. Ammonia or water absorption system,
   b. Ammonia or water or hydrogen electrolux refrigeration syste and
   c. Lithium bromide (LiBr) or water absorption system.

a. Ammonia or Water Absorption System :

1. The most commonly used refrigerant in absorption system is ammonia.
2. It is cheap, readily available and has great affinity with water.
3. It is used as absorbent and absorbs NH_3 very fast.
4. The ammonia-water absorption system is used for cooling – 50 °
5. The main components of this system are shown in Fig. 2.32.1.

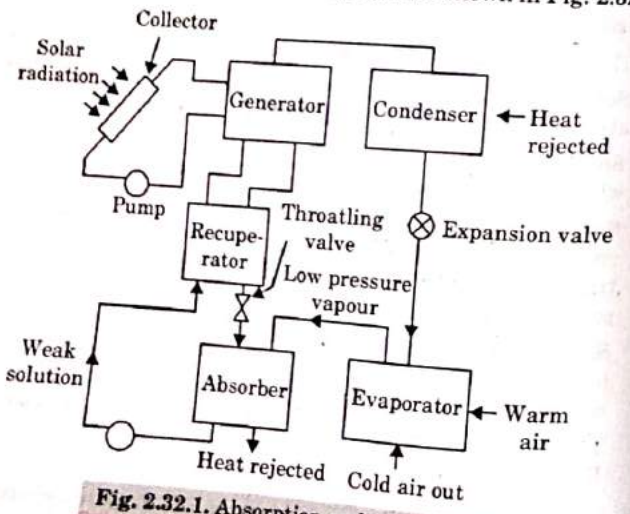


Fig. 2.32.1. Absorption cooling system.

6. The heat required in generator is supplied by water heated in fl plate collector.

7. The hot water transfers the heat to the mixture of absorbent and refrigerant pair, rich of refrigerant.
8. The refrigerant in vapour form enters in the condenser and weak solution returns back in the absorber.
9. In some designs the absorbents are used in the bed of collector.
10. On heating they liberate the water vapour stored in the insulated tank and used for heating the generator during sunshine and off sunshine hours.

Que 2.33. Explain thermal energy storage for solar heating and cooling. What are limitations of solar plants ?

UPTU 2013-14, Marks 10

OR

What are the limitations of solar thermal energy ?

Answer

A. Thermal Energy Storage for Space Heating :

1. The solar energy is utilized for space heating in winter or in colder countries.
2. The different methods adapted for space heating by utilizing the solar energy are passive and active method.
3. Solar space heating reduces the considerable heating load on air conditioning apparatus during winter.

a. Active Space Heating :

1. The active method of space heating utilizes perforated collectors (air heater) through which the cold air is circulated, gets heated and supplied to the living space directly.

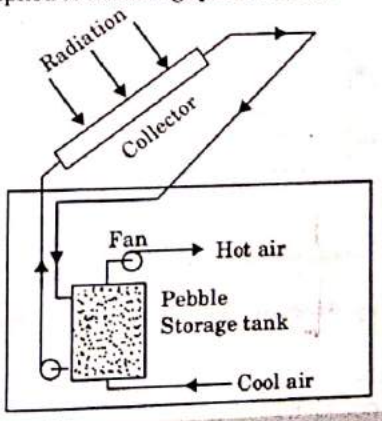


Fig. 2.33.1. Schematic diagram of active space heating by air collector.

2. In other arrangement to utilize this available heat in the night, hot air is first circulated through the tank packed with rocks, gravel or pebbles that serve as a thermal storage.
3. When there is no sunshine or during night the cold air from rooms flow through this pack and after heating get distributed in the living rooms as shown in Fig. 2.33.1.
4. In other arrangement the water heating arrangement is provided through the collectors placed at top of the roof as shown in Fig. 2.33.2.
5. The hot water stored in a storage tank is circulated through the tubes attached to black absorber surface of collector.
6. The heat is delivered to living space by a fan blowing the room air through a heating coil in the heat exchanger, through which hot water from storage tank is circulated in the coils.
7. The heat is extracted by re-circulated air through the exchanger and transferred to the room.
8. The water storage system is more compact than pebble packed system due to higher specific heat capacity of water, but costly because of pump and secondary heat exchanger.

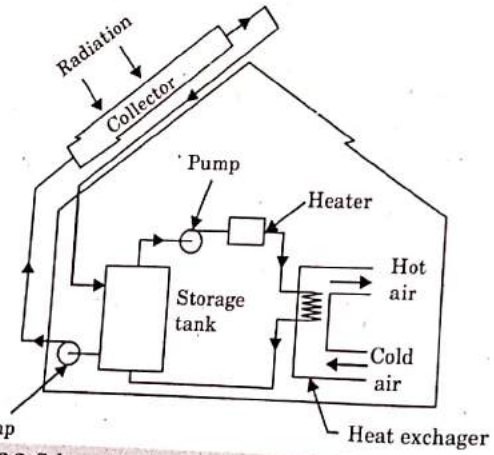


Fig. 2.33.2. Schematic of active space heating by water collector.

B. Thermal Energy Storage for Space Cooling : Refer Q. 2.32, Page 67M, Unit-2.

C. *Limitations :*

1. Large area required for collecting solar thermal energy.
2. Low energy density 0.1 to 1 kW/m^2.

3. Direction of rays changes continuously with time.
4. Energy not available during night and during clouds.
5. Energy storage is essential.
6. High initial cost.
7. Requires hybrid plant with storage facility for supplying energy during night.
8. Solar central power plants in MW range are not economical.

☺☺☺

3 UNIT

Geothermal Energy, MHD and Fuel Cells

PART-1

Resources of Geothermal Energy, Thermodynamics of Geothermal Energy Conversion, Electrical Conversion, Non-Electrical Conversion, Environmental Consideration.

CONCEPT OUTLINE : PART-1

Geothermal Energy : The enormous amount of energy available inside the earth in the form of heat is known as geothermal energy. Geothermal energy is a form of renewable energy and independent of sun, having the source of natural heat inside the earth.

Sources of Geothermal Energy :

1. Hydrothermal resources,
2. Vapour dominated resource,
3. Hot dry rock resource,
4. Geopressure resources, and
5. Magma resource.

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 3.1. **Describe the structure of earth interior.**

Answer

1. Basically earth consists of three layers :

A. Crust :

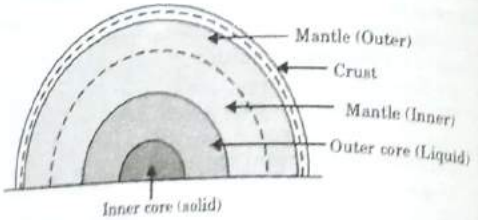
1. It is the uppermost shell of the earth that extends to variable depths below mountains, continents and oceans.
2. The thickness of crust is believed to be 0 to 100 km and several substances like limestone, coal, gold, petroleum etc. are found in the crust.

B. Mantle :

1. It is the second concentric shell of the earth that lies below the crust and this zone starting from the lower boundary of crust and continuous up to a depth of 2900 km.
2. It has been subdivided into an upper and lower mantle. The boundary between the two layers being placed at 900 to 1000 km below the earth.
3. The upper mantle is further divided into two layers of 400 and 600 km thickness respectively.

C. Core :

1. It is the innermost concentric shell of the earth.
2. The core boundary begins at depth of 2900 km from the surface and it extends to the centre of the earth at 6378 km.
3. This layer is further sub divided into outer core and inner core.
4. The outer core comprises the region from a depth of 2900 km to 5100 km below the earth surface and behaves more like a liquid.
5. The inner core with a thickness of around 1278 km is believed to be a solid metallic body.



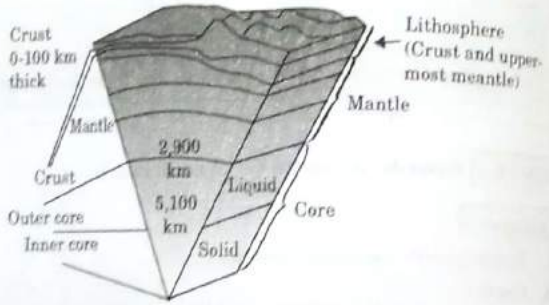


Fig. 3.1.1. Internal structure of earth.

Que 3.2. What is geothermal energy ? Give the classification of geothermal energy resources.

OR

Describe the various types of identified geothermal energy resources and mention its application at different temperatures.

UPTU 2013-14, Marks 10

Answer

1. The earth is a great reservoir of heat energy in the form of molten interior.

2. Surface manifestation of this heat energy is indicated by hot water springs and geysers discovered at several places.
3. Heat can be experienced from the temperature rise of the earth's crust with increasing depth below the surface.
4. Radial temperature gradient increases proportionally to depth at a rate of about 30°C per km. At a depth of 3–4 km, water bubbles up, while at a depth of 10–15 km the earth's interior is as hot as 1000° to 1200°C.
5. The core of the earth consists of a liquid rock known as 'Magma' having a temperature of about 4000°C.
6. This geothermal heat is transferred to the underground reservoir of water which also circulates under the earth's crust. Its heat dissipates into the atmosphere as warm water and the steam vents up through the fissures in the ground as hot springs and geysers.
7. Limitless heat content in magma plus the heat generated by radioactive decay of unstable elements such as K_{40}, Th_{232} and U_{235} which are abundant in earth's crust are forms of geothermal energy and considered as a renewable energy resource.
8. Geothermal resources are of following types :

A. Hydrothermal Resources :

1. These are the deposits of hot water and steam at lesser depths and these can be extracted by means of production well.
2. High temperature water and steam (300° F to 700° F)is used for the generation of electricity, otherwise it is used for space heating.
3. It may be seen that only a part of the rock is permeable constituting the geo-fluid reservoir, so the field is able to produce commercially a viable resource.
4. Examples of Hydrothermal Resource sites :

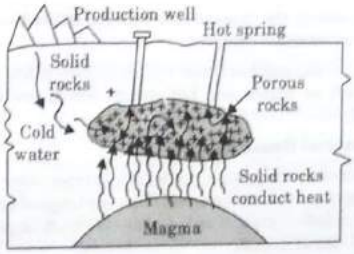


Fig. 3.2.1. Schematic view of hydro-geothermal energy resources.

a. Hot Water Fields :

1. At these locations hot water below 100 °C emit out as hot spring and the geothermal aquifers being covered by confining layers to keep the hot water under pressure.

2. Examples of hot water fields are Sahestra dhara near Dehradun, Surya kund at Badrinath in Uttarakhand, Manikaran in Kullu valley (Himachal Pradesh) and Internationally known fields are Pannonian basin (Hungary), Po river valley (Italy) and Klamath Falls Oregon (USA).

b. Wet Steam Fields :

1. The pressurized water is at more than 100 °C and contains small quantities of steam and vapour in the geothermal reservoir (at 370 °C).
2. Sites where the steam escapes through cracks in the surface are called fumaroles.
3. An impermeable cap-rock prevents the fluid from escaping into atmosphere and drilling is carried out to bring the fluid to the surface.
4. The fluid is used to produce steam and boiling water in predominant phase.
5. Examples of wet steam fields : Los Azufre (Mexico), Puna (Hawaii, USA), Deing (Indonesia), Azores (Portugal) and Latera (Italy).

B. Vapour-Dominated Resources :

1. Vapour dominated reservoirs produce dry saturated steam of pressure above atmospheric pressure and at high temperature about 350 °C.
2. Water and steam coexist, but steam is in dominant phase and regulates pressure in the reservoir.
3. Steam obtained from such a geothermal field directly drives a turbine.
4. Examples : Malsukawa (Japan), The Geysers California (USA), Kamojang (Indonesia) etc.

C. Hot Dry Rock Resources :

1. This is a geological formation with high temperature rocks at 650 °C, heated by conductive heat flow from magma but contains no water.
2. To trap its energy the impermeable rock is fractured and water is injected to create an artificial reservoir.
3. Water circulates and hot fluids return to the surface through the other drilled well as steam and hot water, which are used to generate electricity.

D. Geopressured Resources :

1. These resources contains moderate temperature brines (160 °C) containing dissolved methane and these are trapped under high pressure in a deep sedimentary formation sealed between impermeable layers of shale and clay at depths.
2. When trapped by boring wells, three sources of energy are available :
   a. Thermal,
   b. Mechanical as pressure, and
   c. Chemical as methane.

E. Magma :

1. Magma is a molten rock at temperature ranging from 900 °C to 1600 °C. This hot viscous liquid comes out from active volcanic vents and solidifies.
2. It may form reservoirs at some depth from the earth's surface and magma chambers represent a huge energy source.
3. The existing technology does not allow recovery of heat from these resources.

Que 3.3. What is meant by dry steam, wet steam and hot water geothermal system ? **UPTU 2011-12, 2015-16; Marks 10**

Answer

A. Hot Water Fields :

1. Hot water field, containing a water reservoir at temperature ranging 50-100 °C.
2. Such fields without much steam content can be useful for house heating and agricultural purposes the temperature gradient in this field is less.
3. The reservoir contains water in the liquid phase below the boiling point of water under pressure.
4. On the surface, there are often thermal springs whose temperature is near the boiling point of water. These fields occur at depth less than 2 km.
5. The geyser plant of USA is the largest plant in the world today.

B. Wet Steam Fields :

1. The wet steam fields contain pressurized water in reservoir at temperature higher than 100 °C.
2. When hot water at high pressure is brought to the surface, its pressure is sufficiently reduced and some water will get flashed into steam and remaining in the form of boiling water.
3. The resulting mixture is a mixture of water and steam. Such fields are suitable for power generation.
4. When the well is drilled at such locations, the pressurized water rises into well because of less pressure above the well.
5. The vapour is used directly for producing power while the hot water gets separated in the separator and is used for thermal applications.
6. The percentage of steam generated depends upon the available geothermal fields and more than 90 % of hydrothermal reservoirs exploited on industrial scales are this type.

C. Dry Steam Field :

1. These fields are similar to wet, steam fields but heat transfer from the depth is much higher.

2. These reservoirs produce superheated steam at pressure above atmosphere.
3. The permeability of these fields is lower than wet fields.
4. When the well is drilled up to the reservoir and extraction of fluid starts, a depressed zone is formed at the bottom of the well, that enhances the boiling of water surrounding the rocks.
5. The steam flows through the dry bottom area and starts expanding and gets cool. But the heat added by surrounding rocks at high temperature keeps the steam at superheated state. The degree of superheating may reach up to 100 °C.

Que 3.4. **What is geothermal energy ? Discuss different systems used for generating the power using geothermal energy.**

UPTU 2014-15, Marks 05

OR

Explain geothermal power plants. Write the application of geothermal energy.

Answer

A. **Geothermal Energy :** Refer Q. 3.2, Page 74M, Unit-3.

B. **Different Systems used for Generating the Power :**

a. **Vapour-Dominated Power Plant :**

1. In a vapour-dominated power plant, steam is extracted from geothermal wells, passed through a separator to remove particulate contents and flows directly to a steam turbine.

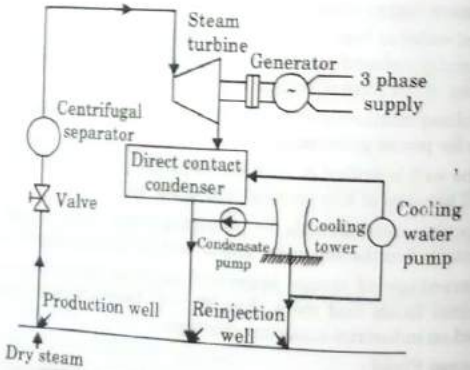


Fig. 3.4.1. Vapour-dominated power plant.

2. Steam then operates the turbine coupled with the generator is at a temperature of about 245 °C and pressure 7 bar which are less than those in conventional steam cycle plants.
3. Thus, the efficiency of geothermal plants is low, *i.e.*, about 20 %.
4. Exhaust steam from the turbine passes through a condenser and the water so formed circulates through the cooling tower.
5. It improves the efficiency of the turbine and controls environmental pollution associated with the direct release of steam into the atmosphere.
6. Waste water from the cooling tower sump is reinjected into the geothermal well to ensure continuous supply.

b. **Liquid-Dominated Power Plants :**

1. These plants are also called wet steam plants because they give wet steam *i.e.*, a mixture of hot water and steam under high pressure.
2. There are two types of liquid-dominated power plants :
   i. Flashed steam system, and
   ii. Binary cycle system.

i. **Flashed Steam System :**

1. Flashed system is preferred for high temperature mixture of geothermal brine and steam, with low dissolved impurities.
2. Geothermal fluid (mixture of brine and steam) passes through a flash chamber where a large part of the fluid is converted to steam.
3. Dry saturated steam passes through the turbine coupled with the generator to produce electric power.
4. Hot brine from the flash chamber and the turbine discharge from the condenser are reinjected into the ground and reinjection of the spent brine ensures a continuous supply of geothermal fluid from the well.

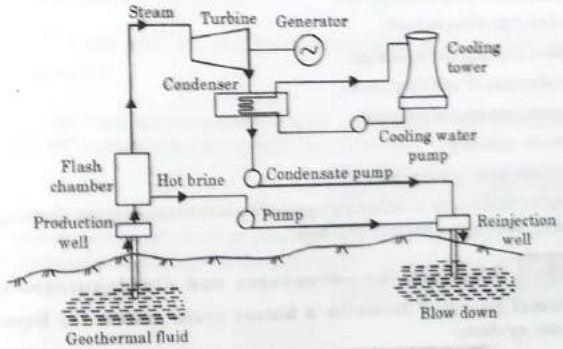


Fig. 3.4.2. Flashed steam geothermal power plant.

ii. **Binary Cycle System :**

1. A binary cycle is used where geothermal fluid is hot water with temperature less than 100 °C.
2. This plant operates with a low boiling point working fluid (Isobutene or Freon) in a thermodynamic closed Rankine cycle.
3. Hot brine from underground reservoir circulates through a heat exchanger and is pumped back to the ground.
4. In heat exchanger, hot brine transfers its heat to the organic fluid thus converting it to a superheated vapour that is used in a standard closed Rankine cycle.

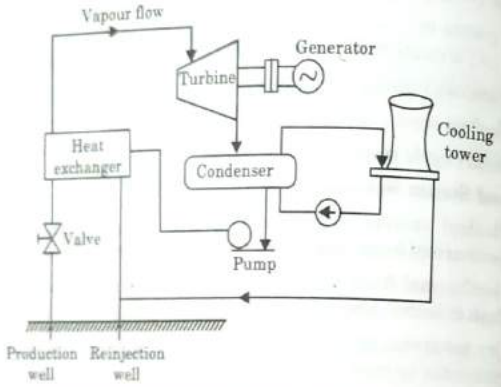


Fig. 3.4.3. Schematic view of binary cycle system.

C. **Applications of Geothermal Energy :**

1. Generation of electric power.
2. Industrial process heat.
3. Space heating for buildings.
4. Production of salt from sea.
5. Extraction manufacturing.
6. Textile industry.
7. Sewage heat treatment.
8. Geothermal water is utilized for greenhouse cultivation using discharge water from a geothermal drill hole.

Que 3.5. **What are the advantages and disadvantages of geothermal energy ? Describe a binary cycle system for liquid dominate system.**

Answer

A. **Advantages :**

1. Feasibility of modular approach represents a lot of opportunities for development of relatively quick, cost effective geothermal projects.
2. The emission of CO_2 and SO_2 by geothermal power plants is far less compared with conventional fossil fuel based power plants.
3. It is almost pollution free.
4. It is an inexhaustible source of energy.
5. More reliable source of power generation than other renewable energy sources.

B. **Disadvantages :**

1. Geothermal fluids often contain significant quantities of gases such as CO_2, CH_4, N_2, NH_3 and H_2S. The H_2S as well as dissolved chemicals can sometimes be acidic. Because of this, corrosion, erosion and chemical deposition may be issues which require attention at the design stage and during operation of the geothermal system.
2. Noise pollution because of drilling.
3. Well casings and pipelines can suffer corrosion and/or scale deposition, and turbines, especially blades, can suffer damage leading to higher maintenance costs and reduced power output.
4. Plants are located at far distance from location of application. This causes more losses in power as well as thermal losses or pressure drops in pipe, while transferring hot fluids (water or steam) for direct use.
5. The underground water depletion may occur at low rainfall areas if water is not reinjected back.

C. **Binary Cycle System for Liquid Dominated System :** Refer Q. 3.4, Page 78M, Unit-3.

Que 3.6. **What are the environmental effects of geothermal energy sourees ?**

OR

Describe the various operational and environmental problems encountered in obtaining the geothermal energy.

UPTU 2015-16, Marks 7.5

OR

Explain a vapour dominated geothermal power plant. What are the environmental constraints in design of geothermal power plants ?

UPTU 2012-13, Marks 10

Answer

A. **Vapour Dominated Geothermal Power Plant :** Refer Q. 3.4, Page 78M, Unit-3.

B. **Environmental Effects of Geothermal Energy Sources :**

1. Geothermal energy is not completely pollution free energy.
2. The main adverse environmental effects are air pollution (waste steam is sometimes vented directly to the atmosphere), thermal pollution (pumping more thermal energy to the atmosphere), surface disturbance, physical effects (land subsidence) caused by fluid withdrawal.
3. At geothermal site, the air pollution is the major problem because of emission of poisonous gases such as hydrogen sulphide (H_2S), ammonia, methane, Carbon dioxide (CO_2) etc.
4. The extraction of energy from hot dry rocks or molten magma, it is necessary to force water down boreholes as a working fluid and return it to surface to use in turbine.
5. If the underground reservoir is highly permeable, there is no way to know how much water will need to be injected before a useful amount of steam or hot water is returned to the surface.
6. A large volume of flash steam escaping into the atmosphere could cause dense fog to occur.
7. At geothermal site, some harmful substances may escape into the air.
8. These may contain radioactive materials also thus systematic monitoring is advisable.
9. Geothermal water contains dissolved solids.
10. The amount of dissolved solids is in the range of 300–1500 ppm of which silica amounts to 25–50 %.
11. The possible solution is reinjection or disposal into sea through ducts and channels and also the use of evaporator ponds.

Que 3.7. **Discuss the difference between a geothermal power plant and thermal power plant. Categories resources of geothermal energy.**

UPTU 2011-12, Marks 10

UPTU 2014-15, Marks 05

OR

Write the difference between a geothermal power plant and thermal power plant.

UPTU 2015-16, Marks 10

Answer

A. **Differences :**

S. No.	Geothermal Power Plant	Thermal Power Plant
1.	It uses inexhaustible source of energy.	It uses exhaustible source of energy.
2.	It is more environment friendly	It is less environment friendly.
3.	These power plants in some dangerous cases can cause earthquakes.	There is no such problem.
4.	It is mainly used for power generations process.	It can be used for various industrial processes.
5.	Setup cost is high.	Setup cost is low.
6.	By products of these plant are not used.	By products of these plant can be used.
7.	These plants are less flexible.	These plants are more flexible.
8.	Specified area are required.	No such restriction.

B. **Resources of Geothermal Energy :** Refer Q. 3.2, Page 74M, Unit-3.

Que 3.8. **Describe a geothermal field from which geothermal steam is obtained through hot springs. What are the prospects of geothermal energy in context to India ?**

UPTU 2013-14, Marks 10

Answer

1. A hot spring is a spring that is produced by the emergence of geothermally heated ground water from the earth's crust.
2. There are hot springs all over the earth, on every continent and even under the oceans and seas.
3. There are the following types of hot springs :
   i. Any geothermal spring.
   ii. A spring with water temperatures above its surroundings.

A. **Geothermal Field :**

1. An area of the earth characterized by a relatively high heat flow.
2. The anomalously high rate of heat flow may be due to present, or fairly recent, orogenic or magmatic activity, or to the radioactive decay of isotopes of K, Th, and U where these occur at very high concentrations in crystal granites (hot dry rocks).

3. In sedimentary basins, low thermal-conductivity values for the rocks are balanced by high thermal gradients, thus maintaining a constant heat flow.
4. The high thermal gradients raise the temperature of deep, permeating water.
5. Extraction of the water up deep boreholes provides surface water at temperatures useful for space heating.
6. Hot springs and fumaroles can be important surface manifestations of a geothermal field.

B. Geothermal Energy Scenario in India :

1. There are about 340 known thermal areas in India, each represented by hot or warm springs.
2. Many more areas are being discovered and reported, in the 12 well defined geothermal provinces.
3. The total stored heat potential of the 93 systems considered is 36.87×10^{18} calories, which is equivalent to the combustion energy of 5160 million tonnes of coal or 25440 million barrels of oil. 38 of these systems are of high temperature type whose heat energy could be considered for electrical power generation.
4. Their estimated cumulative potential for power generation is of the order of about 500 MW for 100 years or 1650 MW for a 30 years period of utilization.
5. Of the remaining thermal areas, 49 are of intermediate temperature and 6 are of low temperature geothermal resources type which could best be used for non-electrical applications.
6. Their cumulative stored heat potential is 19.37×10^8 calories out of which only 1.135×10^8 calories could be beneficially put to practical utilization.
7. Since most of the non-transportation energy needs could be met at temperature below 150-200 °C and if the potentials of all 93 systems are considered for non-electrical applications the cumulative beneficial heat will be of the order of 2.185×10^{18} calories.
8. If this heat is to be supplied from electrical power, 10,000 MW of electricity could be required for 30 years period. Thus these springs have a potential to substitute about 10,000 MW of electricity could be required for 30 years period.
9. This is roughly 10 % of the total anticipated power production in India by the turn of the century.
10. Several pilot projects were undertaken by Geological Survey of India in collaboration with other agencies such as N.A.L. Bangalore, IIT Delhi in the geothermal area of North-West Himalayan province, which have conclusively proved the vast potentialities for exploitation.

11. A pilot project for "space heating" at Puga, in Ladakh in 1975 at a altitude of 4500 m, involved construction of a shed and using steam at 125 °C, at 2.5 kg/cm^2 from a nearby geothermal well for heating the space, with the help of an aluminium finned, copper, tube radiator converter.
12. A difference of 25 °C was achieved with respect to the ambient temperature.
13. Another project named "Green house pilot project" at Chumathang, (Ladakh, 4400 m altitude) in 1974, was commissioned.
14. It utilizes hot water from a nearby geothermal well to heat the soil and environment of a green house separately.
15. Heating of soil was done by laying zig-zag pipes below the complete area of soil and allowing geothermal fluid to pass through them.
16. This project proved that 41 varieties of plant including flowers, creepers, vegetables, and trees can be grown even at the peak of winter using geothermal energy and constructing green house, whereas normally no germination is possible for 10 months in a year in this area.
17. This project was undertaken by Geological Survey of India in collaboration with "Field Research Laboratory" at Leh.
18. A third pilot project "cold storage plant" has been recently commissioned at Manikaran (Himachal Pradesh) by the joint collaboration of Geological Survey of India, IIT Delhi, and Himachal Pradesh Government.
19. This plant avails the hot water at 90 °C from a nearby geothermal well and cold water at 10 °C from the Parbati river, flowing nearby, and is capable of removing 400,000 kcal/hr of heat to obtain a permanent cold storage temperature of 5 °C.
20. This can only possible if successful help the local farmers to store nearly 15,000 tonnes of fruits and potatoes after the harvest and enable them to sell them throughout the year at a uniform price.
21. A 5 kW pilot power plant is under fabrication at National Aeronautical Laboratory, Bangalore.
22. This plant will run on geothermal energy which will be recovered from the hot springs at Manikaran in Himachal Pradesh. This will utilize a binary cycle process using R-113 as the working fluid.
23. All these studies have confirmed the suitability of the resources for utilization for various purposes. Plans are being made to undertake further research and development studies in the area of geothermal energy.

PART-2

Principle of Working of MHD power plant, Performance, and Limitations.

CONCEPT OUTLINE : PART-2

Magneto Hydrodynamics (MHD) : The magneto hydrodynamics deals with generation of electric field, when an ionized fluid at high temperature passes through the applied magnetic field. The direct current is generated from the system with the expense of thermal energy. MHD power generation is based on the Faraday's law of electromagnetic induction.

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 3.9. **Explain the working principle of magneto hydrodynamic power generation.**

Answer

1. In MHD power generation conversion process depends upon Faraday's law of electromagnetic induction, which states that when a conductor and a magnetic field move relative to each other, a voltage is induced in the conductor. This induced voltage produces an electric current.
2. The conductor may be solid, liquid or gas.
3. In MHD generator solid conductors are replaced by hot ionized gas.
4. The hot ionized gas (3000 °C) is passed through the MHD duct across which a strong magnetic field is applied.
5. Since the gases are hot and ionized they form an electrically conducting medium moving in a magnetic field, thus a voltage is generated.
6. The power generated by MHD generator is in the direct current form.
7. Now, if the electrodes are placed in a suitable position then generated current can be extracted.

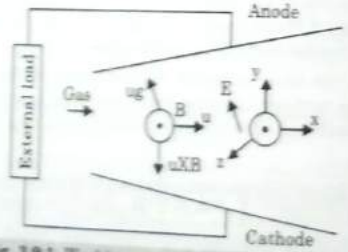


Fig. 3.9.1. Working principle of MHD generator.

Que 3.10. **Derive the equations for the voltage and maximum power output of MHD generator.**

Answer

1. Let a particle, having a charge 'q' moving towards right with velocity v, and a perpendicular magnetic field with flux density 'B' is applied.
2. A magnetic force 'F' acts on the charged particle and given by

$$\vec{F} = q(\vec{v} \times \vec{B}) \qquad ...(3.10.1)$$

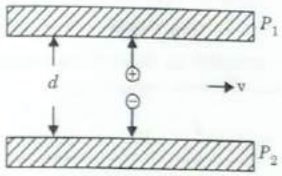


Fig. 3.10.1.

3. Now particle is replace by ionised gas molecules, moving with velocity v.
4. The positive ions accelerated towards plate P_1 and negative ions towards plate P_2.
5. If the plates are connected through a resistance, a current would flow through resistance.
6. Thus, mechanical energy is converted into electrical energy.
7. If an electric field E is also present then equation (3.10.1) becomes

$$\vec{F} = q[(\vec{E} + \vec{v}) \times \vec{B}] \qquad ...(3.10.2)$$

8. In MHD generator, the velocity $\vec{v}$ is the vector sum of gas velocity $\vec{v}_1$ and particle drift velocity $\vec{v}_2$. Therefore,

$$\vec{v} = \vec{v}_1 + \vec{v}_2$$

$$\therefore \quad \vec{F} = q[(\vec{E} + \vec{v}_1) \times \vec{B} + \vec{v}_2 \times \vec{B}] \qquad ...(3.10.3)$$

Let $(\vec{E} + \vec{v}_1) \times \vec{B} = \vec{E}'$, then

$$\vec{F} = q[\vec{E}' + \vec{v}_2 \times \vec{B}] \qquad ...(3.10.4)$$

9. Consider the Fig. 3.10.2, the movement of gas is in X-direction, magnetic field B is in Y-direction and force on the particle is in Z-direction.

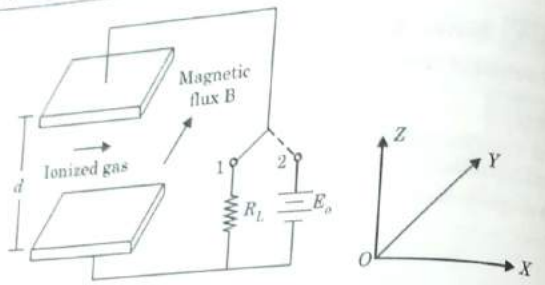


Fig. 3.10.2.

10. When the current 'I' is flowing through the load resistance R_L, then electric field intensity between the plates is

$$\vec{E_Z} = -\frac{V}{d} \qquad ...(3.10.5)$$

Where V is the voltage across load 'R_L' and 'd' is the distance between the plates.

11. Total electric field,

$$\vec{E_Z'} = \vec{E_Z} + \vec{v}_1 \times \vec{B}$$

$$\vec{E_Z'} = -\frac{V}{d} + \vec{v}_1 \times \vec{B}$$

$$\vec{E_Z'} = \frac{1}{d}[d(\vec{v} \times \vec{B}) - V] \qquad ...(3.10.6)$$

12. The electromagnetic field E_Z and B acting on the moving gas produce the same force on the ions as the electromagnetic field E'_Z and B produce on a gas with zero average velocity.

13. Open circuit voltage, $E_o = Bvd$ ...(3.10.7)

14. If R_g is the internal resistance of the generator, then maximum power output is obtained when

$$R_g = R_L$$

$$P = E_o I = I^2 R_g \qquad ...(3.10.8)$$

$$I = \frac{E_o}{R_g + R_L}$$

$$\therefore \quad P = \left(\frac{E_o}{R_g + R_L}\right)^2 R_g$$

Put $R_g = R_L$, then

$$P_{max} = \frac{E_o^2}{4R_g} \qquad ...(3.10.9)$$

$$\therefore \quad R_g = \frac{d}{\sigma A} \qquad ...(3.10.10)$$

where, σ = Conductivity of gas, and
A = Area of the plate.

So, $$P_{max} = \frac{E_0^2 \sigma A}{4d} \qquad ...(3.10.11)$$

15. From equation (3.10.7) and equation (3.10.11),

$$P_{max} = \frac{B^2 v^2 \sigma \, dA}{4} \qquad ...(3.10.12)$$

$$\therefore \text{ Maximum power per unit volume} = \frac{B^2 v^2 \sigma}{4} \qquad ...(3.10.13)$$

Que 3.11. Write short notes on the following :

a. Open cycle MHD system, and
b. Closed cycle MHD system.

OR

How are magneto hydrodynamic system classified ? Describe them in brief. **UPTU 2012-13, Marks 10**

OR

Draw schematic diagram of a MHD power generating system with a heat recovery system. Explain the working of system. **UPTU 2011-12, Marks 10**

OR

Give the principle of MHD power generator. Explain in detail the closed MHD system. **UPTU 2014-15, Marks 10**

Answer

A. **Working Principle of MHD :** Refer Q. 3.9, Page 86M, Unit-3.

B. **Classification of Hydrodynamic System :**

a. **Open Cycle MHD System :**

1. The open cycle MHD generator uses coal as a fuel as it produces more conductive plasma. This is because of more carbon atom as compared to hydrogen atom (as the presence of hydrogen is undesirable in MHD).
2. Fig. 3.11.1 shows the schematic diagram of an open cycle MHD generator.

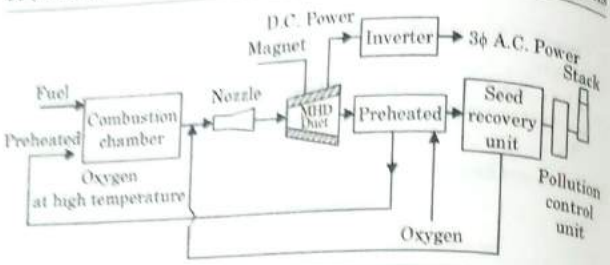


Fig. 3.11.1. Open cycle MHD generator.

4. The working temperature in the open cycle MHD generator lies approximately in the range above 2300 °C.
5. This is a lower temperature limit and below this the effective electrical conductivity becomes zero.
6. There may be no limit in the upper working temperatures, so far the materials can stand with the high heat fluxes under high electric field.

b. Closed Cycle MHD System :

1. Fig. 3.11.2 shows the schematic diagram of closed cycle MHD generator.

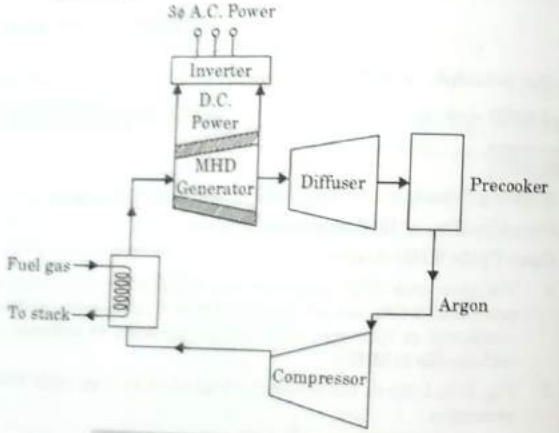


Fig. 3.11.2. Closed cycle MHD generator.

2. The very high thermal efficiency is achieved with low cycle cost in closed cycle plant and provides more useful power at low temperature at 1600 °C. The duct of these units is small because of high pressure.

3. Helium or argon is used as working fluid, heated in heat exchanger and gets ionised.
4. Less ionised substances such as alkali metal is mixed with inert gas to provide the necessary conductivity in closed cycle plant, where recovery is possible.
5. The closed cycle plant is further classified in seeded inert gas system and liquid metal system.
6. The working fluid (argon or helium) in closed cycle is seeded with cesium and circulates in a close loop.
8. The gas burned in the combustor is supplied in the heat exchanger, where the heat is transferred to the working fluid.
9. The ionised working fluid passes through the magnetic field to produce DC power.
10. The combustion products are discharged to the atmosphere after removal of heat in heat exchanger.

i. Closed Cycle Liquid Metal MHD Generator :

1. Fig. 3.11.3 shows the schematic diagram of closed cycle liquid metal MHD generator.
2. The superheated metallic vapour is expanded through the supersonic nozzle and enters in the generator in liquid form with velocity of 150 m/s.
3. The electrical conductivity of metallic vapour is poor. That brings the overall conversion efficiency lower than that of gas as a working substance.
4. However it has the advantages to supply the AC current directly and there is no need of inverter.

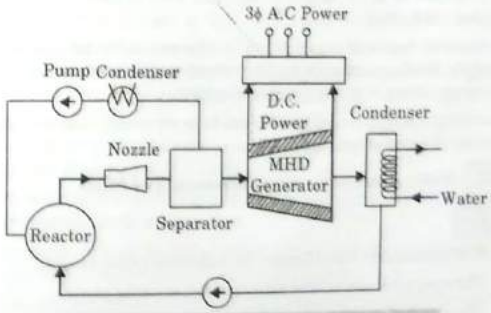


Fig. 3.11.3. Closed cycle liquid MHD generator.

6. In nuclear fired MHD generator the high temperature nuclear reactor is used to utilize solid fuel elements to meet the requirements.

7. The ceramic coated electrodes are film cooled by hydrogen to protect them from unusual build up of uranium droplets.
8. The cyclonic separators are used to remove the uranium droplet from the hydrogen gas and the hydrogen flows in the compressor expands through the turbine, then is cooled in heat exchangers in multistage compression.

Que 3.12. Why is seeding necessary for the working fluids used in MHD generator ?

Answer

1. The electrical conductivity of hot gases is too low as it depends on how many ions and electrons are available in the ionization gas (plasma) for carrying the electric charge as well as on the strength of applied magnetic field.
2. The conductivity of the gas can be increased by ionization of gas at high temperature above 3000 °C, but it limits the material used at that temperature.
3. Therefore another way to improve or increase the conductivity of ionized gas is seeding.
4. The seeding is carried out to increase the conductivity of fluids and is a non-thermal ionization process of gases.
5. The molecules of some materials *i.e.*, cesium or potassium, having lower ionization energy are added to the working gases used in MHD.
6. These molecules split off the electrons generated during collision of high temperature gases molecules to form ions.
7. The presence of more negative charged ions makes the gas more electrical conductive.
8. The required degree of conductivity is achieved at low temperature by adding the seeding materials and is in direct proportion to square root of the concentration of seeding material added.
9. The seeding material is costly and needs to be recovered from the exhaust to reduce the cost of seeding plant.

Que 3.13. Write short note on requirements of MHD.

Answer

1. The MHD generator should meet the following requirements :
   a. The magnet material should have high melting point.
   b. The electrodes are made of SiC or ZrC material to withstand high temperature for preventing the chemical erosion.
   c. To prevent the chemical erosion from hot gases the ceramics are chosen to construct the duct.

   d. Duct material should have high electrical and thermal insulation.
   e. The insulation and conducting materials should be able to withstand high temperature around 2500 °C.

Que 3.14. What are the advantages and disadvantages of MHD generator ?

OR

Explain the working principle of MHD generator. Also discuss the practical problems associated with MHD power generator.

UPTU 2013-14, Marks 10

Answer

A. Working Principle of MHD : Refer Q. 3.9, Page 86M, Unit-3.

B. Advantages :

1. The conversion efficiency is high (60–65 %) because of higher operating temperature. This reduces the cost of MHD plant by 20 % compared to a conventional plant.
2. Less wear and tear because of no moving parts and needs less maintenance.
3. Less pollution to the environment because of less fuel consumption as compared to other conventional plants. This is because of high efficiency.
4. Instant operation and is suitable as peak load plant.
5. Less costly than coal fired steam and gas power plant.
6. MHD generators are compact, have low specific weight and high power density.
7. Less operating cost.
8. No mechanical linkage is required because of absence of rotating shaft.

C. Disadvantages :

1. As the power of MHD is directly proportional to square of magnetic flux, it needs very large power to create it and increases the cost of the system.
2. The life of the equipment exposed to high temperature gases is less because of corrosion and chemical erosion.
3. There are problems for manufacturing duct, heat exchanger and reactor to withstand high temperature.
4. The residue from burning coal is carried out along with combustible gases and causes erosion to exposed surfaces.
5. High temperature around 2500 °C is required to ionize the gases.
6. The reverse flow of electrons occurs at the end of magnetic field, through the conducting gases.
7. High thermal and frictional (12 %) losses are involved.

D. Practical Problems Associated with MHD :

1. The main problem in the design of long-life MHD generators is to find the materials that can survive high operating temperatures of these generators. Both the insulator and conducting materials should sustain temperature of 2500 °C for prolong duration.
2. Electrode materials are chemically eroded by combustion gases.
3. Seed material potassium attacks insulating materials and makes them conducting.
4. The major problem forced by this generator is the economics. Although the overall thermal efficiency is 60 %, against 40 % for conventional thermal plant, additional investment in the magnet, generator, duct, compressors, scrubbers, seed recovery plant and DC to AC converters may increase the plant cost and it may be much higher than conventional plant.

PART-3

Principle of Working of Various Types of Fuel Cells and Their Working, Performance and Limitations.

CONCEPT OUTLINE : PART-3

Fuel Cell : Fuel cell is a electrochemical device that converts chemical energy into electricity and heat without combustion. Whereas, the conversion of chemical energy into electrical energy in case of fuel cell is an isothermal process.

Types of Fuel Cell :

1. Alkaline fuel cells (AFC),
2. Direct methanol fuel cells (DMFC),
3. Phosphoric acid fuel cells (PAFC),
4. Proton or polymer exchange membrane fuel cells (PEMFC),
5. Molten carbonate fuel cells (MCFC),
6. Solid oxide fuel cells (SOFC),
7. Zinc air fuel cells (ZAFC), and
8. Regenerative fuel cells (RFC).

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 3.15. **What do you understand by fuel cell ? How fuel cells are classified ? Describe an H_2O_2 fuel cell with a sketch showing reactions.**

OR

What is fuel cell ? Describe the principle of working of a H_2O_2 cell. Give also limitations. **UPTU 2013-14, Marks 10**

OR

Describe the principle of working of a fuel cell with reference to hydrogen oxygen cell. Also discuss advantages and limitations of fuel cells. **UPTU 2012-13, 2015-16; Marks 10**

Answer

A. Fuel cell :

1. A fuel cell is an electro-chemical device that converts chemical energy into electricity and heat without combustion.
2. The conversion of chemical energy into electrical power in case of fuel cell is an isothermal process.
3. Main components of a fuel cell are :
   1. Anode (Fuel electrode), 2. Cathode (Oxidant electrode),
   3. Electrolyte, 4. Container,
   5. Separators, 6. Sealings,
   7. Fuel supply, and 8. Oxidant supply.

B. Type of Fuel Cell :

1. Alkaline fuel cells (AFC),
2. Direct methanol fuel cells (DMFC),
3. Phosphoric acid fuel cells (PAFC),
4. Proton or polymer exchange membrane fuel cells (PEMFC),
5. Molten carbonate fuel cells (MCFC),
6. Solid oxide fuel cells (SOFC),
7. Zinc air fuel cells (ZAFC), and
8. Regenerative fuel cells (RFC).

C. Working Principle of Hydrogen Oxygen Cell :

1. A basic hydrogen-oxygen fuel cell with phosphoric acid as electrolyte is shown in Fig. 3.15.1.
2. In fuel cells, platinum coated special graphite plates are used as the electrodes, separated by an electrolyte.
3. The fuel is hydrogen gas which is supplied at the anode side where the hydrogen molecules are effectively reduced to hydrogen ions which move to the electrolyte.

$$H_2(gas) \longrightarrow 2H^+(ion) + 2e^-$$

4. Electrons liberated at the anode build up a negative potential and travel towards the cathode through an externally connected circuit.
5. Oxygen gas is supplied at the cathode where it is reduced by hydrogen ions to produce water.

$$4H^+ + O_2 + 4e^- \longrightarrow 2H_2O$$

6. Electrochemical reactions coupled with movement of hydrogen ions through the electrolyte generate an electric potential, which causes electric current to flow through the load.

$$2H_2 + O_2 \xrightarrow{\text{Fuel cell}} 2H_2O + \text{Electric energy generated} + \text{Heat energy released}$$

This reaction is exothermic, which results in heating up the cell.

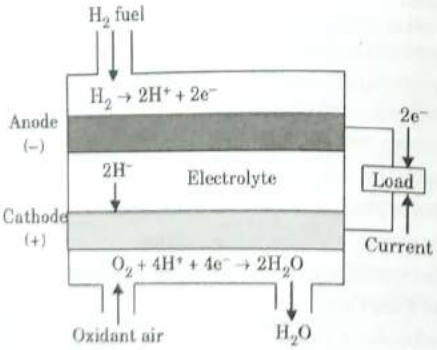


Fig. 3.15.1. Fuel cell operation.

7. A stream of air is circulated on the cathode side of the cell which absorbs enough heat to maintain outlet air and steam at 180 °C which is optimum for best performance of the cell.

C. Advantages of Fuel Cell :

1. Fuel cell has high efficiency.
2. Fuel cell is simple and safe.
3. Fuel cell does not have moving parts.
4. Fuel cells are compact and noiseless.
5. They are pollution free.
6. No cooling water needed.
7. The capacity can be increased as the demand grows.
8. Space requirement is much less.
9. It has long life.
10. It is odourless and quiet in application.

D. Limitations of Fuel Cell :

1. The reactivity and invariance are the two general requirements for all fuel cells. To satisfy the reactivity requirement, it is necessary that we have proper stoichiometry and also require high electrode activity, which results in large current densities.
2. The second requirement, invariance, means that a fuel cell should only be a converter of energy and should remain unlike a conventional battery, invariant throughout its life. This requirement implies no corrosion or side reactions, no change in the electrolyte and no change in the electrodes.
3. If the fuel cell is operated near room temperature, then it would deliver little electricity.

Que 3.16. Write down the disadvantages and applications of hydrogen oxygen fuel cell ?

Answer

A. Disadvantages of Fuel Cell :

1. Initial cost of the cell is high.
2. Problems for refilling in vehicles.
3. The life is short because of degrading of electrodes.
4. Unsafe to handle and there are chances of explosion because of hydrogen and oxygen.
5. Efficiency of cell goes down to 30 – 40 % with internal reformer.

B. Applications of Fuel Cell :

1. It is used in automotive vehicles.
2. It is used in domestic power unit.
3. It is used in central power station.
4. It is used in military and aerospace.
5. For remote and inaccessible locations, fuel cell can be used unattended for a long period.

Que 3.17. Explain the working of molten carbonate fuel cells using appropriate diagram and write the various chemical reactions involved in this type of fuel cell.

Answer

A. Molten Carbonate Fuel Cell (MCFC) :

1. It uses an electrolyte, which is a molten mixture of carbonate salts.
2. Two mixtures commonly used are :
   a. Lithium carbonate and potassium carbonate, and
   b. Lithium carbonate and sodium carbonate.

3. Since, these salts can act as electrolytes only in liquid phase, the operating temperature should be as high as 650 °C.
4. Due to high temperature, these salts melt and become conductive to carbonate ions (CO_3^{--}).
5. These ions flow from the cathode to the anode where they combine with hydrogen to give water, carbon dioxide and electrons.
6. The electrons flow through external circuit and reaches to cathode, generating electricity and byproduct heat.
7. The reactions are given below :

Anode reaction : $CO_3^{--} + H_2 \longrightarrow H_2O + CO_2 + 2e^-$
Cathode reaction : $CO_2 + 1/2\ O_2 + 2e^- \longrightarrow CO_3^{--}$
Total reaction : $H_2 + 1/2\ O_2 + CO_2 \longrightarrow H_2O + CO_2$

8. The emf produced by each cell is theoretically 1 V and actual emf of 0.8 V at 700 °C and the expected efficiency is about 60 %.

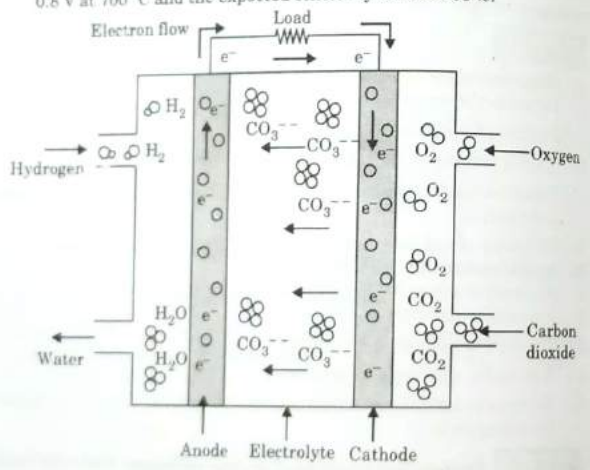


Fig. 3.17.1. Molten carbonate fuel cell.

Que 3.18. **Explain polymer or proton electrolyte membrane fuel cell and write desired properties of an ideal electrolyte of this fuel cell.**

Answer

A. Proton Electrolyte Membrane Fuel Cell (PEMFC) :

1. In this type of fuel cell, electrolyte is a solid polymer membrane of an organic material such as polystyrene sulphonic acid and this polymer is

permeable to protons when it is saturated with water but it does not conduct electrons.
2. In PEMFC, the fuel is hydrogen and charge carriers are hydrogen ions (protons).
3. At the anode, the hydrogen molecule is split into hydrogen ions and electrons.
4. The hydrogen ions penetrate across the electrolyte to cathode while the electrons flow through an external circuit and produce electric power.
5. Oxygen is supplied to the cathode and combines with electrons and the hydrogen ions to produce water.
6. The reactions are given below :

Anode reaction : $2H_2 \longrightarrow 4H^+ + 4e^-$
Cathode reaction : $O_2 + 4H^+ + 4e^- \longrightarrow 2H_2O$
Total reaction : $2H_2 + O_2 \longrightarrow 2H_2O$

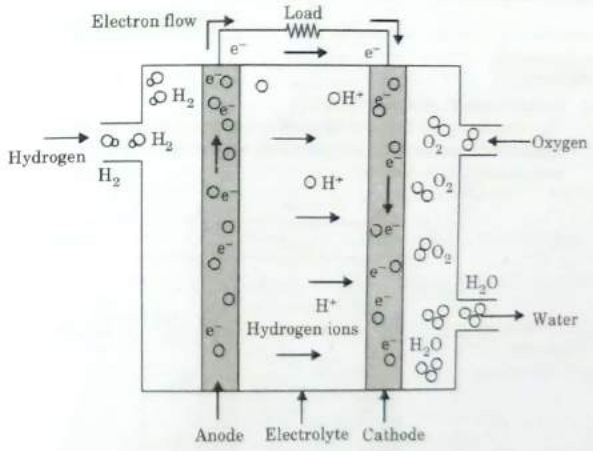


Fig. 3.18.1. PEMFC

7. The membrane is coated on its both sides with finely powdered platinum which acts as a catalyst. These cells are also called ion exchange membrane cell.

B. Advantages of PEMFC :

1. It has high power density.
2. It can be start rapidly.
3. Less expensive.

4. It has less problems with corrosion.
5. It has longer life.
6. It operates at low temperature *i.e.*, usually below 100 °C.

C. **Disadvantage :**

1. The main disadvantage of this type of cell is that due to low operating temperature these are not enough to perform useful cogeneration.

D. **Desirable Properties of an Ideal PEMFC Electrolyte :**

1. High ionic conductivity.
2. Zero electronic conductivity.
3. Low permeability of fuel and oxidant.

Que 3.19. **Describe solid oxide fuel cells.**

OR

Sketch and explain the functioning of solid oxide fuel cells.

UPTU 2011-12, Marks 10

Answer

A. **Solid Oxide Fuel Cells (SOFC) :**

1. The electrolyte in this cell is a solid, non porous metal oxide that is conductive to oxygen ions and these cells are operate at high temperature between 650 °C to 1000 °C.

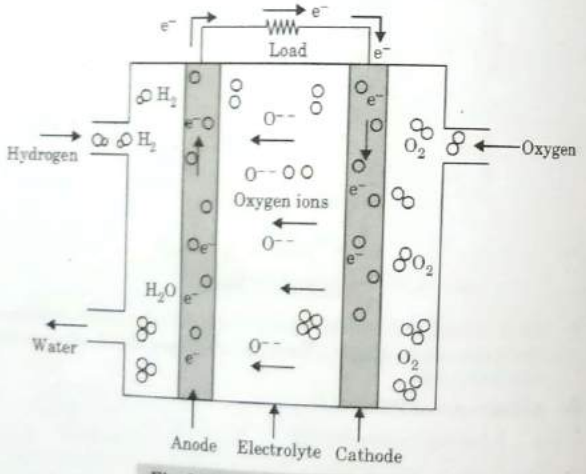


Fig. 3.19.1. Solid oxide fuel cells.

2. At the cathode, the oxygen molecules from the air are split into oxygen ions with the addition of four electrons.
3. The oxygen ions are conducted through the electrolyte and combine with hydrogen at the anode releasing four electrons.
4. The electrons move through the external circuit producing electric power and byproduct heat.
5. The reactions are as followed :

Anode reaction : $2H_2 + 2O^{--} \longrightarrow 2H_2O + 4e^-$

Cathode reaction : $O_2 + 4e^- \longrightarrow 2O^{--}$

Total reaction : $2H_2 + O_2 \longrightarrow 2H_2O$

6. The output voltage is about 0.65 V at about 800 °C and a tubular type of SOFC system has been developed which operates at high temperature of about 900 °C – 1000 °C.

Que 3.20. **Describe the performance analysis for fuel cell.**

OR

Show that a hydrogen-oxygen fuel cell has a maximum efficiency of 83 %.

Answer

A. **Performance Analysis for Fuel Cell :**

1. In a fuel cell, a chemical reaction takes place where the reactants are converted into products in a steady flow process.
2. The work is obtained by combining the first and second laws of thermodynamics as follows.
3. According to first law of thermodynamics for a steady flow process,

$$\Delta Q - \Delta W = \Delta H + (\Delta KE) + (\Delta PE)$$

where, ΔQ = Heat transferred to the steady flow stream from the surroundings,

ΔW = Workdone by the flow stream from entrance to exit,

ΔH = Change in enthalpy of the flow stream from entrance to exit,

KE = Kinetic energy of the stream, and

PE = Potential energy of the stream.

4. In this case, KE and PE are usually negligible. Hence equation can be written as,

$$\Delta W = \Delta Q - \Delta H \quad ...(3.20.1)$$

5. According to second law of thermodynamics,

$$\Delta Q = T\Delta S \quad ...(3.20.2)$$

6. On combining equation (3.20.1) and (3.20.2), we get

$$\Delta W_{max} = T\Delta S - \Delta H \quad ...(3.20.3)$$

7. The Gibbs free energy is given by

$$\Delta G = \Delta H - T\Delta S \text{ (where } T \text{ is constant)} \quad ...(3.20.4)$$

8. From equation (3.20.3) and equation (3.20.4), we get

$$\Delta W_{max} = -\Delta G$$

B. Efficiency :

1. The efficiency (η_F) of energy conversion of a fuel cell is defined as the ratio of the useful work to the heat of combustion of the fuel.

   Mathematically,

$$\eta_F = \frac{\Delta W_{max}}{(-\Delta H)} = \frac{-(\Delta G)}{-(\Delta H)} \quad ...(3.20.5)$$

2. For hydrogen-oxygen fuel cell, ΔG is (–237191) J/kg-mol at 25 °C while its heat of reaction ΔH is about (–285838) J/kg-mol.

$$\eta_{max} = \frac{237191}{285838} = 0.829 \approx 83\ \%$$

C. EMF of a Fuel Cell :

1. The electromotive force that will drive electrons through external load is proportional to Gibbs free energy change.

   Mathematically,

$$E = \frac{-\Delta G}{nF} \quad ...(3.20.6)$$

   Where, E = Electromotive force,
   ΔG = Change in Gibbs free energy (J/mol),
   n = Number of electrons per mole of fuel, and
   F = Faraday's constant = 96500 coulombs/mole.

2. From equation (3.20.5) and equation (3.20.6), we get

$$\eta_{max} = \frac{nFE}{\Delta H} = \frac{-I.t.E}{\Delta H}$$

   Where, I = Current, and
   t = Time for which current flows.

3. The overall efficiency of fuel cell is given as

$$\eta_{overall} = \eta_F \times \text{Loss factor}$$

4. The power output of a reversible fuel cell is given by

$$P_{rev} = \frac{\Delta G_{max}}{\text{Molar mass of hydrogen}}$$

   Where, molar mass of hydrogen = 2.018 kg/mole

5. Actual electrical power output, $P = P_{rev} \times \eta_{overall}$
6. The rate of heat released, $Q = P_{rev} - P$

Que 3.21. Discuss the *V-I* and *P-I* characteristics of fuel cells.

Answer

A. Current-Voltage Characteristics :

1. The actual cell potential is decreased from its equilibrium potential because of irreversible losses, activation polarization, internal polarization and concentration polarization. These losses are called polarization voltage losses.

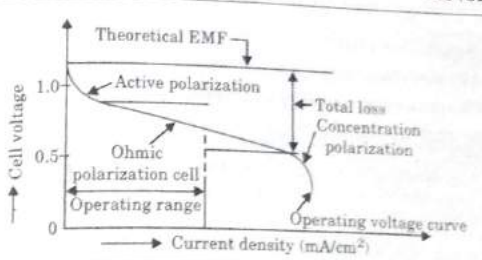


Fig. 3.21.1. Current-voltage characteristics of fuel cell.

2. These losses cause cell voltage (V_C) to get reduced.
3. The cell voltage drops with increase in current density because of polarization losses and it is given by

$$V_C = E - \Delta V_p$$

   Where, E is an ideal or no load voltage potential of cell.

5. With increase in load on the cell, the internal losses increase and drop in cell terminal voltage occurs.

B. Power-Current Characteristics :

1. The power of fuel cell increases in cell current density and decreases after saturation point is reached, because of polarization effect.
2. The power of cell starts decreasing with increase in cell current after saturation point, because of high thermal losses. The power of cell is given by :

$$P = V_c \times I_c$$

4. Therefore, power of cell increases with increase in cell current, but this will also increase the polarization losses and saturation point will be reached where power of the cell will be maximum.

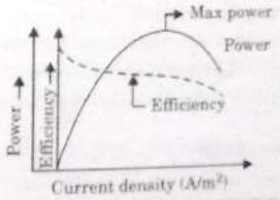


Fig. 3.21.2. Current density (A/m²)

Que 3.22. What is fuel cell ? Differentiate between AFC and PEMFC.

UPTU 2014-15, Marks 05

Answer

A. Fuel Cells : Refer Q. 3.15, Page 95M, Unit-3.

B. Difference between AFC and PEMFC :

S. No.	AFC	PEMFC
1.	It operates between the temperature ranges of 40 °C - 200 °C.	It operates between the temperature ranges of 40 °C - 90 °C.
2.	It uses H_2 as a fuel.	It uses H_2, CH_4, CH_3OH as a fuel.
3.	KOH used as electrolyte.	Polymer used as electrolyte.
4.	The power density of this cell is in the range of 0.1 – 0.3 W cm^2.	The power density of this cell is in the range of 0.7 W cm^2.
5.	It is mainly used for power generation on spacecrafts.	It is mainly used for transport applications.

Que 3.23. Give the requirements of electrolyte and electrode and the characteristics of a fuel cell.

Answer

A. Requirements of Electrolyte :

1. It should be conductive to ions.
2. It should be electrically non conductive.
3. Ions should be free to move through the electrolyte.
4. The composition of electrolyte should not get changed during operation.

B. Requirements of Electrode :

1. It should be electrically conductive.
2. It should not react with electrolyte to prevent corrosion.
3. It should be able to withstand at high temperature.
4. It should also act as a catalyst to convert hydrogen and oxygen molecules into their ions.

C. Characteristics of Cell :

1. It should have high energy conversion efficiency.
2. It should produce low chemical pollution.
3. It should be flexible to choose any fuel.
4. It should have cogeneration capability and rapid load response.

Que 3.24. What is the difference between fuel cell and a battery ? Explain the working function of solid oxide fuel cells with heat sketch.

OR

Explain the difference between a fuel cell and battery. What are the uses and advantages of fuel cells ? **UPTU 2011-12, Marks 10**

Answer

A. Difference between Fuel Cell and Battery

S. No.	Fuel Cell	Battery
1.	The fuel cell is a primary cell and cannot be recharged but can be refueled.	The battery is rechargeable.
2.	The fuel and oxidizer do not mix together.	Fuel and oxidizer are not used separately.
3.	Fuel and oxidizer need continuous replacement as per requirement.	Battery stores fixed charges of chemical, used up during reaction.
4.	It produces electricity continuously as long as fuel oxidizer is supplied.	Battery stores energy.

B. Working Function of Solid Oxide Fuel Cells : Refer Q. 3.19, Page 100M, Unit-3.

C. Advantages of Fuel Cells : Refer Q. 3.15, Page 95M, Unit-3.

D. Applications of Fuel Cell : Refer Q. 3.16, Page 97M, Unit-3.

Que 3.25. Describe the fuel cell power station system.

Answer

1. The main components of a fuel cell power plant is shown in Fig. 3.25.1.
2. Electrical energy is generated from primary fossil fuels through a fuel cell.
3. Fuel is managed and supplied by a fuel processing unit. In this unit, fuel is received, stored, reformed, purified and supplied to fuel cell modules.
4. Fuel cell modules convert fuel energy electrochemically into DC power using ambient air as oxidant.
5. Basic configurations of cell, module and plant are shown in Fig. 3.25.2.
6. A number of cells are stacked to form a module.
7. Several modules are interconnected to form a power generating unit.

8. Fuel gas and air are supplied to modules from common supply pipes.
9. The exhaust is collected in a common pipe and discharged to the atmosphere directly or after recovery of heat in a cogeneration unit.
10. The power generating unit generates electrical power as DC.
11. Industrial / commercial loads are rated for standard AC supply such as 3f, 400 V, 50 / 60 Hz or 1f, 230/110 V, 50/60 Hz.
12. The electrical power conditioning unit, converts DC output of fuel cell to AC using inverter and also controls and regulates it.

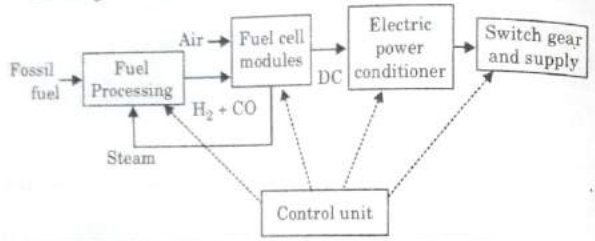


Fig. 3.25.1. Fuel cell based electrical generation scheme.

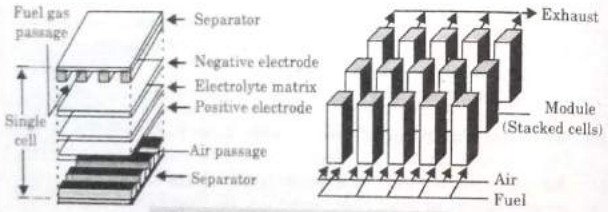


Fig. 3.25.2. Power generation unit.

Que 3.26. Discuss briefly fuel cell powered vehicles and their features.

Answer

1. The fuel cell vehicle shown in Fig. 3.26.1, is ecofriendly compared with conventional vehicle.
2. They include fuel cell which uses hydrogen, reformed methanol etc. as a fuel.
3. The hydrogen gas at high pressure (350 bar) and low temperature (around – 235 °C) is stored in high pressure tank mounted on the vehicle.
4. It can also use liquid fuels such as gasoline or methanol that can be stored in non pressurised tank, and can be converted to hydrogen by the reformer.

5. These vehicles are refueled at refueling station as the gasoline vehicles do.
6. The fuel stacks generates power to run the vehicle by electricity.

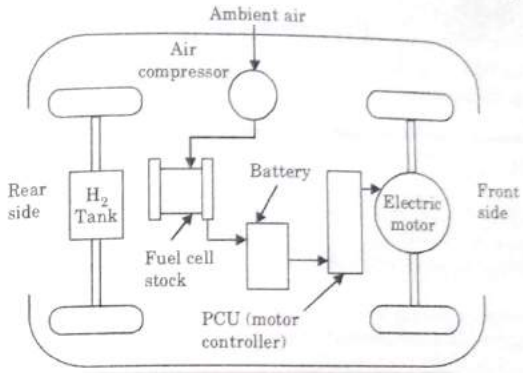


Fig. 3.26.1. Components of fuel cell vehicle.

A. Features :

1. They are highly efficient (30 % – 40 %) compared to gasoline vehicles (15 % – 20 %).
2. Longer distance coverage before refueling.
3. These vehicles are zero emission vehicles and do not emit CO_2, NO_x, CO and other particulates.
4. Use of fossil fuel gets reduced.
5. Low noise level.
6. Various types of fuels can be used in fuel cells, *e.g.* natural gas, ethanol etc.

☺☺☺

4 UNIT

Thermoelectrical and Thermionic Conversion and Wind Energy

PART-1

Thermoelectrical and Thermionic Conversion : Principle of Working, Performance and Limitations.

CONCEPT OUTLINE : PART-1

Thermoelectrical Conversion : In thermoelectric conversion, heat energy (thermal energy) is converted into electrical energy through semiconductors or conductors. This process is based on the Seebeck effect.

Thermionic Conversion : In thermionic conversion, heat energy is directly converted into electrical energy by utilizing thermionic emission effect. In such a device, electrons are emitted from the surface of heated metal. The energy required to extract an electron from the metal is known as work function and expressed in electron volt. The work function depends upon the nature of metal and its surface condition.

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 4.1. **Explain the following : Joule effect, Thomson effect, Peltier effect.**

OR

Briefly describe :

a. **Seebeck effect, and**

b. **Peltier effect.** **UPTU 2014-15, Marks 10**

Answer

a. **Seebeck Effect :**

1. It states that if a closed circuit is made of two dissimilar metals and the two junctions are maintained at different temperatures than an emf is setup in circuit.
2. The magnitude of current depends on both the metals (1 and 2) and the temperature difference between the junctions.
3. The emf produced is function of the difference in temperature between hot and cold junction, and is given by

$$E = \alpha_s \Delta T$$

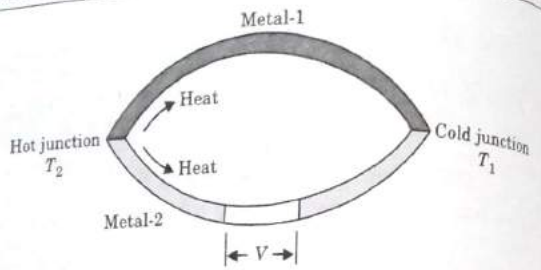


Fig. 4.1.1. Seebeck effect principle of thermocouple.

Where, ΔT = Difference between hot and cold junction, and
α_s = Seebeck coefficient.

b. Peltier Effect :

1. When an electric current flows across an isothermal junction of two dissimilar materials, there is either an evolution or absorption of heat at the junction. This effect is called the Peltier effect.
2. The Peltier coefficient α_p is defined as the heat evolved or absorbed at the junction per unit current flow per unit time.
3. Mathematically,

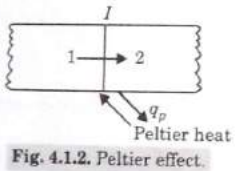


Fig. 4.1.2. Peltier effect.

$$\alpha_{p1\text{-}2} = \alpha_{p1} - \alpha_{p2} = \frac{q_p}{I}$$

and $$q_p = \alpha_{p1\text{-}2} I$$

Where, I = Peltier heat per unit time.

c. Joule Effect :

1. In a closed electrical circuit, if the current I flows through a resistance R, the heat generated by the resistance is equal to I^2R. It is known as Joule effect.
2. The expression is given by

$$Q = I^2R$$

d. Thomson Effect :

1. It states that "any current carrying conductor with a temperature difference between two points will either absorb or emit heat, depending upon the material."

2. The Thomson coefficient (σ) is defined as the heat absorbed (or evolved) per unit time per unit electric current and per unit temperature gradient.
3. Mathematically,

$$\sigma = I \frac{dq_T/dx}{dT/dx}$$

Where, $\frac{dq_T}{dx}$ = Heat interchange per unit time per unit length of conductor,

$\frac{dT}{dx}$ = Temperature gradient, and

I = Current

4. Hence, the Thomson heat per unit time is given by

$$\frac{dq_T}{dx} = \frac{\sigma I dT}{dx}$$

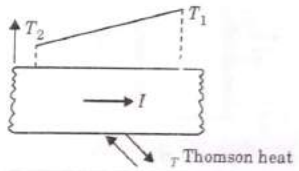


Fig. 4.1.3. Thomson effect.

A. Relationships between the Seebeck, Peltier and Thomson Coefficients as Derived by Kelvin are as follows :

1. The first Kelvin relation exists between the Seebeck coefficient and Peltier coefficient by the relation :

$$\alpha_p = \alpha_s . T$$

or $$\alpha_{p1\text{-}2} = \alpha_{s1\text{-}2} T$$

2. The second Kelvin relation exists between the Seebeck coefficient and Thomson coefficient by relation :

$$\sigma = T \frac{d\alpha_s}{dT}$$

or $$\sigma_{1\text{-}2} = T \frac{d\alpha_{s_{1\text{-}2}}}{dT}$$

Que 4.2. Describe the working of a thermoelectric generator. Derive an expression for its power output.

UPTU 2013-14, Marks 10

OR

Explain the working of a thermoelectric generator. Derive an expression for its power output. **UPTU 2015-16, Marks 7.5**

Answer

A. Principle : The principle is based on Seebeck effect.
Refer 4.1, Page 109M, Unit-4.

B. Construction :

1. It consists of two dissimilar metals A and B respectively with their end joined together at point C which is kept at higher temperature.

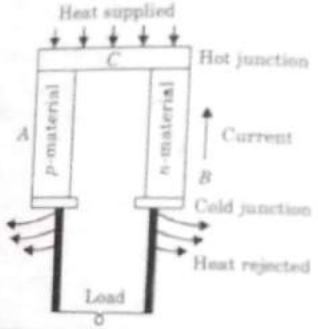


Fig. 4.2.1. Thermoelectric generator.

2. The other end of metals A and B is kept at low temperature and induced voltage which is measured by connecting the potentiometer at these free ends.
3. The simplest thermoelectric generator consists of a thermocouple, comprising a p-type and n-type material.

C. Working :

1. Consider a metal bar whose one side is kept at a higher temperature than the other.
2. If the free electrons in the metal are considered to behave as a gas, the kinetic theory of gases predicts that the free electrons in the hot side of the bar will be on higher kinetic energy and will be moving at greater speed than those in the cold side of the bar.
3. As the faster moving electrons flow from the hot side to the cold side of the bar, it results in an accumulation of negative charge at the cold side and prevents further charge build up until circuit is closed.
4. In a closed circuit, the current will flow to reduce the charge build up and will continue to flow as long as the temperature gradient is maintained.

D. Advantages :

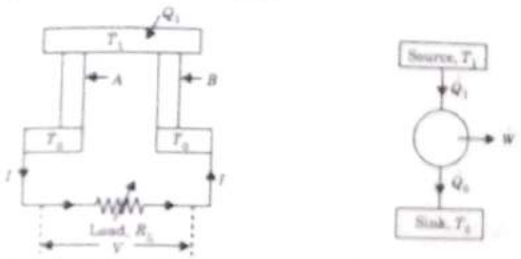
1. It is highly reliable.
2. It is free from noise due to absence of moving parts.

3. It is compact and has long life.
4. It requires minimum maintenance.
5. It is portable and used at any location.
6. It uses low grade thermal energy.

E. Disadvantages :

1. High cost.
2. Low efficiency.
3. Low output.

F. Expression for Power Output :



(a) Single thermocouple generator. (b) Schematic diagram.

Fig. 4.2.1. Efficiency of thermoelectric generator.

1. Let, T_1 = Temperature of source (K),
T_0 = Temperature of sink (K),
L = Length of thermoelectric materials (m),
A = Area of thermoelectric materials (m^2),
k = Thermal conductivity of materials (W/m-K),
ρ = Electrical resistivity of materials (ohm-m),

K = Thermal conductance of materials, $\frac{kA}{L}$ (W/K),

R = Electrical resistance of elements, $\frac{\rho L}{A}$ (ohm),

α = Absolute value of Seebeck coefficients (V/K), and
π = Absolute value of Peltier coefficient (V).

1. Suffix A and B are used for respective materials and suffix L is used for load resistance.
2. Consider hot plate as control volume and the Seebeck voltage, $V = \alpha_{AB} \cdot (T_1 - T_0)$ is generated as a result of current flow I in the circuit when the load R_L is placed in the circuit.

3. The heat rate into hot plate $\dot{Q}_1$ is balanced by the heat conducted into two legs $\dot{Q}_k$ and the Peltier heat $\dot{Q}_p$ at the junction due to current flow in the circuit and the Joulian heat $\frac{\dot{Q}_j}{2}$ flows into each junction assuming that half the heat appears at each junction.

4. According to 1st law of thermodynamics, the energy balance equation can be written as :

$$\dot{Q}_1 + \frac{\dot{Q}_j}{2} = \dot{Q}_p + \dot{Q}_k \quad ...(4.2.1)$$

Where, $$\dot{Q}_p = \pi_{AB} \times I = \alpha_{AB} \times I \times T_1 \quad ...(4.2.2)$$

$$\dot{Q}_j = (R_A + R_B) I^2 = \left[\frac{\rho_A \cdot L_A}{A_A} + \frac{\rho_B \cdot L_B}{A_B}\right] \cdot I^2 \quad ...(4.2.3)$$

$$\dot{Q}_k = (K_A + K_B)(T_1 - T_0) = \left[\frac{k_A \cdot A_A}{L_A} + \frac{k_B \cdot A_B}{L_B}\right](T_1 - T_0) \quad ...(4.2.4)$$

5. On substitution,

$$\dot{Q}_1 = \alpha_{AB} \cdot I \cdot T_1 + \left[\frac{k_A \cdot A_A}{L_A} + \frac{k_B \cdot A_B}{L_B}\right](T_1 - T_0) - \frac{1}{2}\left[\frac{\rho_A \cdot L_A}{A_A} + \frac{\rho_B \cdot L_B}{A_B}\right] I^2 \quad ...(4.2.5)$$

6. Useful power generated is,

$$\dot{W}_L = I^2 \cdot R_L = \frac{V_L^2}{R_L} \quad ...(4.2.6)$$

Where, $V_L = \alpha_{AB}(T_1 - T_0) - I(R_A + R_B)$ ...(4.2.7)

7. By Kirchhoff's law,

$$I = \frac{V}{R} = \frac{\alpha_{AB}(T_1 - T_0)}{R_A + R_B + R_L} \quad ...(4.2.8)$$

8. Let the resistance ratio, m be defined as

$$m = \frac{R_L}{R_A + R_B} \quad ...(4.2.9)$$

Hence, $$(1 + m) = \frac{R_A + R_B + R_L}{R_A + R_B}$$

9. On putting the value from equation (4.2.9) in equation (4.2.8), we get

$$I = \frac{\alpha_{AB}(T_1 - T_0)}{(1 + m)(R_A + R_B)} \quad ...(4.2.10)$$

10. Power output from equations (4.2.6), (4.2.9) and (4.2.10) can be written as,

Power generated,

$$\dot{W}_L = \frac{|\alpha_{AB}(T_1 - T_0)|^2 \times (R_A + R_B)m}{(1 + m)^2 (R_A + R_B)^2}$$

i.e., $$\dot{W}_L = \frac{m}{(1 + m)^2} \times \frac{|\alpha_{AB}(T_1 - T_0)|^2}{(R_A + R_B)} \quad ...(4.2.11)$$

11. From equation (4.2.5), the rate of heat input becomes,

$$\dot{Q}_1 = \alpha_{AB} \frac{\alpha_{AB}(T_1 - T_0)}{(1 + m)(R_A + R_B)} T_1 + (K_A + K_B)(T_1 - T_0) - \frac{1}{2}(R_A + R_B) \frac{\alpha_{AB}^2 (T_1 - T_0)^2}{(1 + m)^2 (R_A + R_B)^2}$$

$$\dot{Q}_1 = \frac{\alpha_{AB}^2 T_1 (T_1 - T_0)}{(1 + m)(R_A + R_B)} + (K_A + K_B)(T_1 - T_0) - \frac{1}{2} \frac{\alpha_{AB}^2}{(1 + m)^2} \times \frac{(T_1 - T_0)^2}{(R_A + R_B)} \quad ...(4.2.12)$$

12. Efficiency of the generator can be written as :

$$\eta = \frac{\dot{W}_L}{\dot{Q}_1}$$

On substituting the values of $\dot{W}_L$ and $\dot{Q}_1$ from the equation (4.2.11) and equation (4.2.12) and on solving we get,

$$\eta = \left(\frac{T_1 - T_0}{T_1}\right) \frac{m}{(1 + m) - \frac{1}{2}\left(\frac{T_1 - T_0}{T_1}\right) + \frac{(K_A + K_B)(R_A + R_B)(1 + m)^2}{\alpha_{AB}^2 \cdot T_1}}$$

13. We define figure of merit as :

$$Z = \frac{\alpha_{AB}^2}{(R_A + R_B)(K_A + K_B)}$$

Z consists of material properties of semiconductors A and B only.

14. Thus efficiency will increase with increase in Z.

15. The Seebeck effect can be +ve or –ve. High magnitude of Z is required with high value of Seebeck coefficient (opposite polarity), low resistivity and low thermal conductivity.

16. For high efficiency, (Z. T) should be as high as possible.

17. The maximum power output and maximum efficiency are given by the relations :

$$Z_{(opt)} = \left[\frac{\alpha_{AB}}{\sqrt{\rho_A \cdot k_A} + \sqrt{\rho_B \cdot k_B}}\right]^2$$

$$\left(\dot{W}_L\right)_{max} = \frac{1}{4}\frac{\alpha_{AB}^2 \cdot (T_1 - T_0)^2}{(R_A + R_B)}$$

$$\eta_{max} = \left(\frac{T_1 - T_0}{T_1}\right) \cdot \frac{1}{2 - \frac{1}{2}\left(\frac{T_1 - T_0}{T_1}\right) + \frac{4}{Z_{opt} \cdot T_1}}$$

Que 4.3. **What are the different types of semiconductor used in thermoelectric power generation ? What are the criteria for the selection of these materials ? Describe a thermoelectric generator.**

Answer

A. Semiconductor used in Thermoelectric Power Generation :

1. Bismuth telluride (Bi_2Te_3).
2. Lead telluride (PbTe).
3. Germanium telluride (GeTe).
4. Cesium sulphide (CeS).
5. Zinc antimonide (ZnSb).

B. Criteria for Material Selection :

1. High Seebeck coefficient.
2. High electrical conductivity.
3. Low thermal conductivity.
4. It should have high resistance to corrosion.
5. It should have high elastic strength to prevent damage at high temperature.

C. Thermoelectric Generator : Refer Q. 4.2, Page 111M, Unit-4.

Que 4.4. **What is a thermionic converter ? How does it works ? What are its major limitations ?**

OR

Describe the principle of operation and constructional details of basic thermionic generator, **UPTU 2012-13, Marks 10**

OR

What do you understand by thermionic emission effect ? Derive the expression for power and efficiency of a thermionic generator.

UPTU 2013-14, Marks 10

Answer

A. Thermionic Emission Effect :

1. If a metal is heated, electrons are emitted from it; this is thermionic emission.

2. The thermal energy supplied to the solid results in an increase of the amplitude of the lattice vibrations. The resulting collisions with free electrons within the metal are then more energetic, so that it is possible for an electron to receive sufficient energy to expel it from the metal altogether
3. The energy required to extract an electron from the metal is an important parameter, known as the work function of the metal.
4. Thermionic emission is the process that is common to all materials and occurs at all temperature.
5. However the currents that can be produced are extremely small except in the special case of metals at high temperatures.

B. Thermionic Converter (or Generator) :

a. Principle :

1. A thermionic converter (or generator) converts heat energy directly into electrical energy by utilizing thermionic emission effect.
2. In this device, electrons act as the working fluid in place of a vapour (or gas) and electrons are emitted from the surface of heated metal.

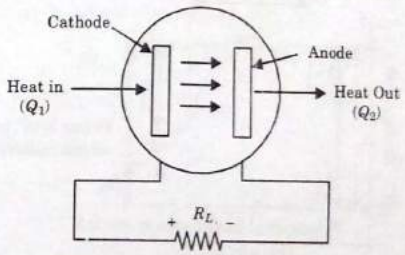


Fig. 4.4.1. Thermionic converter.

B. Work Function :

1. It is defined as the energy required to extract an electron from the metal.
2. The value of work function varies with the nature of metal and surface conditions.

C. Construction : It consists of the following :

a. Anode (Negatively Charged Electrode) :

1. It is a colder collector electrode into which vapourized electrons are condensed after conduction through the inter-electrode plasma and it must be cooled to avoid back emission of electrons.

b. Cathode (Positively Charged Electrode) :

1. It is a hot emitter electrode from which electrons are vapourized by thermionic emission at high temperatures due to heat input and it has higher work function than anode.

D. Working :

1. A metal electrode called emitter is heated until it releases electrons from its surface and flow towards the anode.
2. The electrons cross the small gap between the electrodes and accumulate on a cooled metal electrode called collector.
3. The work function of emitter should be higher than that of collector.
4. In order to minimize the energy losses, as the electrons move across the gap, the space between the electrodes is either maintained at high vacuum or it is filled by a high conducting plasma like ionized cesium vapour.
5. The electrons enter the collector and return through the external circuit back to the emitter, thus it produces electrical power.
6. The energy of electrons emitted by a cathode is partially rejected to the heat sink from anode and the remainder is converted into electrical power.

E. Power and Efficiency of Thermionic Converter :

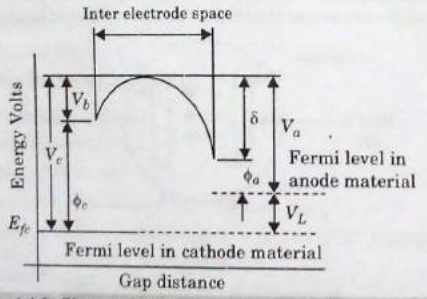


Fig. 4.4.2. Characteristic curve of thermionic converter.

1. Let
   ϕ_c = Work function of cathode,
   ϕ_a = Work function of anode,
   V_b = Kinetic energy barrier at cathode,
   V_L = Load voltage,
   δ = Space charge, and
   T_c and T_a = Temperature of cathode and anode respectively.
2. The total energy required at cathode, $V_c = \phi_c + V_b$
3. Current density of cathode is given by,

$$J_c = AT_c^2 \exp\left(\frac{-V_c}{KT_c}\right)$$

4. Similarly, current density of anode is given by,

$$J_a = AT_a^2 \exp\left(\frac{-V_a}{KT_a}\right)$$

4. Load voltage (output), $V_L = V_c - V_a = \phi_c - \phi_a$
5. Energy required to reaching the electrons at anode,
   $Q_1 = (\phi_c + V_b) \times J_c = V_c \times J_c$
6. The electrons also carries the energy in the form of kinetic energy $(2KT_c)$ is,

$$Q_2 = J_c \frac{2KT_c}{e}$$

7. Therefore, total energy needed for electron to reach to the anode,

$$Q_c = Q_1 + Q_2 = J_c V_c + J_c \frac{2KT_c}{e}$$

$$= J_c\left(V_c + \frac{2KT_c}{e}\right)$$

8. Similarly, back emission from anode carries the energy is given by,

$$Q_a = J_a V_a + J_a \frac{2KT_a}{e}$$

$$= J_a\left(V_a + \frac{2KT_a}{e}\right)$$

9. The net energy supplied to cathode,

$$Q_{net} = J_c\left(V_c + \frac{2KT_c}{e}\right) - J_a\left(V_a + \frac{2KT_a}{e}\right)$$

10. Power output $(P) = V_L(J_c - J_a)$
11. The efficiency of converter $(\eta) = \dfrac{P}{Q_{net}}$

$$= \frac{V_L(J_c - J_a)}{J_c\left(V_c + \frac{2KT_c}{e}\right) - J_a\left(V_a + \frac{2KT_a}{e}\right)}$$

$$= \frac{(V_c - V_a)(J_c - J_a)}{J_c\left(V_c + \frac{2KT_c}{e}\right) - J_a\left(V_a + \frac{2KT_a}{e}\right)}$$

Let $\dfrac{V_c}{KT_c} = \gamma_c$

$\dfrac{V_a}{KT_a} = \gamma_a$

And $\dfrac{T_a}{T_c} = T'$

$$\therefore \quad \eta = \frac{(\gamma_c - T'\gamma_a) \times [1 - T'^2 \exp(\gamma - \gamma_a)]}{(\gamma_c + 2) - T'^2(\gamma_a + 2T')\exp(\gamma_c - \gamma_a)}$$

12. If $\gamma_a = \gamma_c = \gamma$ then

$$\eta_{max} = (1-T')\frac{\gamma}{\gamma+2}\left[\frac{1-T'^2}{1-\frac{T'^2(\gamma+2T')}{\gamma+2}}\right]$$

$$= (1-T')\frac{\gamma}{\gamma+2} \qquad \left[\because \frac{1-T'^2}{1-\frac{T'^2(\gamma+2T')}{\gamma+2}} \approx 1\right]$$

F. Advantages :

1. Absence of rotating parts.
2. It is a compact device.
3. It operates at high temperatures.
4. It is quiet in operation, long life, low cost and has low maintenance.
5. It can operate in remote areas and harsh environment.
6. It has higher conversion efficiency.
7. It can be developed for very low power to very high power generation.

G. Disadvantages :

1. It needs high operating temperature at anode.
2. It needs special seal to protect the cathode from corrosive gases.
3. It needs the cesium vapour in the tube to reduce the space charge.
4. Metal is costly as it has to withstand high temperatures.

H. Applications :

1. It can be installed anywhere at the place of use.
2. Thermionic power can be developed at centralized location and distributed for various commercial and residential applications.
3. It is suitable for military and space applications.
4. These generators are suitable for use with nuclear reactor or radio-isotope heat sources.

Que 4.5. Explain the working of thermoelectric generator. Differentiate between thermoelectric and thermionic conversion system.

UPTU 2011-12, 2014-15; Marks 10

Answer

A. Working of Thermoelectric Generator : Refer 4.2, Page 111M, Unit-4.

B. Difference Between Thermoelectric and Thermionic Conversion System :

S. No.	Thermoelectric Conversion System	Thermionic Conversion System
1.	A thermoelectric converter is a form of heat engine which takes up heat at an upper temperature (hot junction) converts it partly into electrical energy and discharges the remaining part at a lower temperature (cold junction).	A thermionic converter is a form of heat engine that uses an electron gas as a working substance.
2.	The efficiency of thermocouple as in case with other heat engines increases by increasing the upper temperature and decreasing the lower temperature.	A thermionic converter works because of the phenomenon of "thermionic emission" of electrons from the metal when it is heated.
3.	Since the lower temperature is usually that of environment, the efficiency of a thermocouple practically depends upon the hot junction temperature.	A thermionic converter consists of two metals or electrode with different work function is maintained at a higher temperature than one with the smaller work function.

PART-2

Wind Power and its Source, Site Selection Criterion, Momentum Theory, Classification of Rotors, Concentrations and Augments, Wind Characteristics Performance and Limitations of Energy Conversion Systems.

CONCEPT OUTLINE : PART-2

Wind Energy : Wind carries enormous quantity of energy. Wind power has been used for centuries to sail vessels, pump water, grinding grain. Before the development of electric power on large scale, wind power has served many countries as source of power in early days and was called as wind mills. Modern wind mills equivalent to a wind turbine can use the wind energy to generate electricity.

Classification of Wind Turbines :

1. Horizontal-axis turbines, and
2. Vertical-axis turbines.

Types of Rotor :

1. Multiblade type,
2. Propeller type,
3. Savonius type, and
4. Darrieus type.

The first two are installed in horizontal-axis turbines, while the last two in vertical-axis turbines.

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 4.6. **What do you understand by "Wind" ? What are the causes of wind ?**

Answer

1. The movement of air is called wind which is created by the pressure difference between two uneven heated places.
2. Wind is air in motion and it derives energy from solar radiation
3. Wind energy is a clean, eco-friendly, safe and renewable source of energy.

A. Causes of Wind : Basically there are two causes of wind :

1. Uneven heating of the earth's surface (local winds), and
2. The rotation of earth around its axis (planetary winds).

a. Local Winds : Local winds are caused by unequal heating and cooling of ground surfaces and water bodies in day and night *i.e.*, lake, sea, desert etc.

b. Planetary Winds :

i. Planetary winds are caused by the rotation of the earth about its axis and the combined effect of difference in temperature at equator and polar region.

ii. Because of this, warm air from tropical regions flows upward and moves towards the poles and cool air from poles move towards the tropical region.

Que 4.7. **Discuss the following parameters :**

1. **Pitch Angle**
2. **Pitch Control**
3. **Tip Speed Ratio**
4. **Solidity**
5. **Hub**
6. **Propeller**
7. **Nacelle**
8. **Yaw Control.**

Answer

1. **Pitch Angle :** Angle between the direction of wind and direction perpendicular to the plane of blades.
2. **Pitch Control :** It is the control of pitch by turning the blades or blade tips.
3. **Tip Speed Ratio :** The ratio of the speed of the rotor blade tips to the speed of the wind is known as tip speed ratio.
4. **Solidity :** It is the ratio of the projected area of the rotor to the swept area of the rotor.

OR

Solidity is defined as the percentage of the circumference of the rotor which is filled by the rotor blades.

$$\text{Solidity } (s) = \frac{N.b}{\pi d}$$

Where, N = Number of blades,
b = Average breadth of blade, and
d = Diameter of the circle described by a blade.

5. **Hub :** Central solid part of the wheel.
6. **Propeller :** Revolving shaft with blades.
7. **Nacelle :** Assembly consists of wind turbine, gears, bearings, generator etc., mounted in a housing.
8. **Yaw Control :** Control of orienting the axis of wind turbine in the direction of wind.

Que 4.8. **What do you understand by nature of wind ? Describe with the help of a neat sketch the construction and working of a wind energy conversion system (WECS).** **UPTU 2013-14, Marks 10**

OR

Classify rotors employed for wind generation. Prove that for propeller type, horizontal axis wind turbine.

UPTU 2011-12, Marks 10

OR

Describe the working of wind energy conversion system (WECS) with main components.

OR

Give the classification of wind mills.

Answer

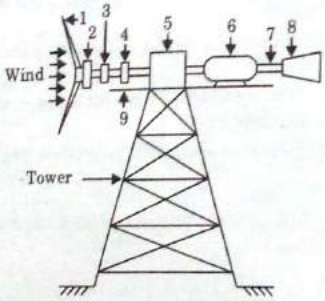
A. Nature of Wind : Refer Q. 4.6, Page 122M, Unit-4.

B. Wind Energy Conversion System and Classification of Rotors :

There are two types of wind energy conversion system :

a. Horizontal Axis Wind Turbine (HAWT) Generator :

1. The components of a horizontal axis wind turbine is shown in Fig. 4.8.1.



1. Rotor with blades
2. Electromagnetic brakes
3. Controller
4. Mechanical brakes
5. Gear box
6. Generator
7. Shaft
8. Flap or tail vane
9. Tower top

Fig. 4.8.1. Wind generator.

2. In horizontal axis wind turbine, the propeller are of two types *i.e.*,
   a. Up wind, and
   b. Down wind.
3. In up wind type, the blades are slanted and wind approaching the blades from front side and nacelle is placed on rear side of the blade (nacelle having propeller, gears and generator).
4. In down wind design, wind approaching blades from nacelle side.
5. HAWT are divided according to the blade mounted on hub :
   i. Mono-blade, ii. Twin-blade,
   iii. Three-blade, and iv. Multi-blade.

i. Mono-Blade :

1. The mono-blade HAWT are simple in construction and lighter in weight, low price, easy to install and have easy maintenance.
2. Mono-blade turbines are equipped with synchronous generator and experience minimum stress on bearing.
3. This HAWT produce low power of 15 kW to 50 kW with length of the blade varying from 15 – 25 m.

Applications : Pumping, battery charging and power supply to farmhouses.

ii. Twin-Blade :

1. Twin-blade HAWT is less costly than three-blade type but have large vibrations while running.
2. The teething control is provided with these machines to reduce the fatigue on main shaft.
3. These machines are rated from 1 to 3 MW.

iii. Three-Blade :

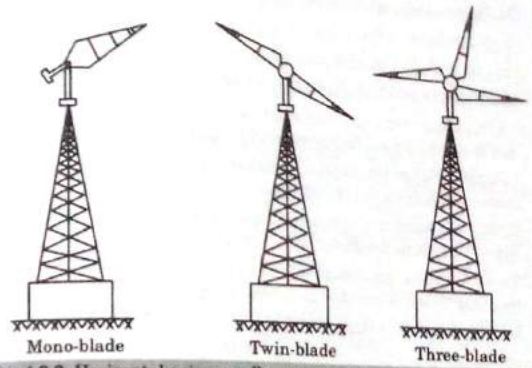


Fig. 4.8.2. Horizontal axis propeller type wind turbine generator unit.

1. Three-blade HAWT has a 3-phase synchronous generator or a 3-phase induction generator to operate at constant speed and axis of nacelle is oriented so that plane of turbine blades is perpendicular to wind direction.
2. To change the generator shaft speed, a gear chain is provided from turbine shaft.
3. This HAWT produce smaller to larger unit *i.e.*, from 15 kW to 3 MW units.

iv. Multi-Blade :

1. The multi-blade turbines are high solidity turbine used for pumping the water because of high starting torque characteristics.
2. The multi-blade rotors are less efficient because of interference of blades in each other but they are less noisy.

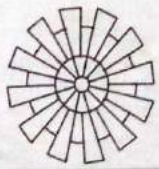


Fig. 4.8.3. Multi-blade.

Advantages :

i. Energy cost/kWh is lower.
ii. Higher power generation.

Disadvantages :

i. Design is complex and involves control problems.

ii. High stress develops at the time of large wind speed.

iii. Repair, installation and maintenance are difficult.

b. Vertical Axis Wind Turbine (VAWT) Generator :

1. Vertical axis wind turbines are also known as cross-wind axis turbine and the axis of rotation is perpendicular to the direction of the wind.
2. In VAWT, the generator can be placed at base level or within the support tower and nacelle is not required.
3. VAWT are omni directional and do not need the yaw control to orient the rotor axis in the direction of wind.
4. These turbines are mounted on ground level and have blades that go from top to bottom which look like an egg beaters.
5. VAWT stands 30 m tall and 15 m wide.

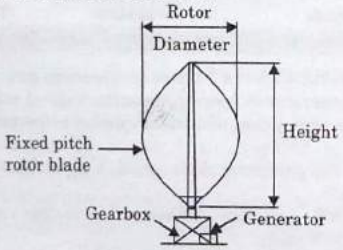


Fig. 4.8.4. Vertical axis.

6. VAWT are classified into three categories :

i. Savonius :

1. The rotor of these turbines are 'S' shaped and supported at top and bottom by two circular plates.

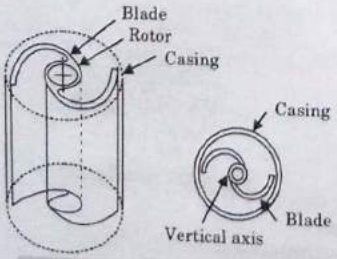


Fig. 4.8.5. Savonius wind turbine.

Fig. 4.8.6. Savonius rotor (S-shaped).

2. Savonius rotor rotates for air flow in any direction and they are self starting, and having low speed and low efficiency.
3. This is a drag type VAWT turns relatively slow, but yields a high torque.

Advantages :

1. This type of rotor operates at low velocity of wind.
2. There is no need of yaw and pitch control.
3. Generator can be mounted at the ground level.
4. Low cost.

Applications : It is useful for grinding grains, pumping water etc.

ii. Darrieus :

1. These turbines have vertical blades that rotate into and out of the wind and by using aerodynamic lift, these turbines can capture more energy than drag devices.
2. The rotor rotates on two bearing placed on top and bottom of pipe, with wind blowing from any direction. But the rotor is not self starting and needs auxiliary starter.
3. The wind turbine is anchored on ground by wire ropes and generator is mounted on the ground.

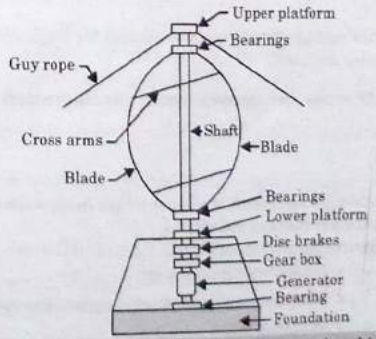


Fig. 4.8.7. Vertical axis darrieus type wind turbine.

Advantages :

1. The generator, gear box etc. are placed on the ground.
2. No need of yaw mechanism to turn the rotor against the wind.

Disadvantage :

1. These turbines suffer a problem of stalling when wind speed is very high.

iii. H-shape Rotor :

1. In this type of turbine, two vertical blades are joined by a horizontal beam to form H-shape and the horizontal beam is mounted on the tower with hub at the centre of the horizontal beam.
2. H-rotor and horizontal beam are designed as aerodynamic foils and H-shape rotates around the vertical axis.

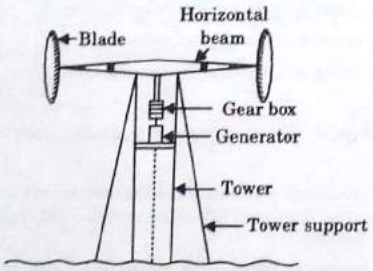


Fig. 4.8.8. VAWT with H-shape rotor.

3. In this type, the generator is placed at the upper part and coupled with the rotor through gear system.
4. The blades of the rotor are either fixed type or variable shape in terms of angle.
5. For smaller ratings fixed type is used and for higher ratings variable shape blades are used.

Que 4.9. Discuss the aerodynamic consideration in wind mill design.

Answer

1. Aerodynamics is the branch of science which deals with air and gases in motion and their mechanical effects.
2. Nomenclature of aerodynamics :

v = Impinging wind velocity,

v_T = Wind velocity in plane of rotation due to blade turning,

v_R = Resultant wind velocity,

F_L = Lift force perpendicular to v_R,

F_D = Drag force perpendicular to v_R,

F_R = Resultant force on blade,

F_T = Component of F_R producing torque,

F_{th} = Thrust force component,

α = Angle of attack, and

β = Pitch angle.

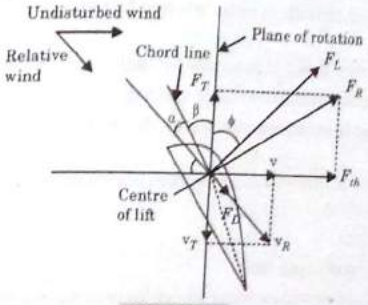


Fig. 4.9.1.

3. Blade is moving in the plane of rotation and it sees a tangential wind velocity v_T in the plane of rotation.
4. v_R is the resulting wind velocity, which is the vector sum of tangential velocity v_T and impinging wind velocity v.
5. The lift force F_L acts perpendicular to the resultant velocity v_R and the drag force F_D is parallel to v_R.
6. The vector sum of lift force F_L and drag force F_D is F_R.
7. Now resolve F_R into two forces *i.e.*, F_T which is torque producing component and F_{th} thrust producing component.
8. The tower and structural members of the wind turbine must be designed to withstand F_{th}.
9. The vector diagram is centred on the centre of lift of the aerodynamic blade.
10. The angle of attack (α) is very important parameter and it determines lift and drag forces.

Que 4.10. Describe with a neat sketch, the working of a WECS with main components. What are the main factors to be considered for the selection of a site for wind generators ?

UPTU 2014-15, Marks 10

OR

What parameters are to be considered while selecting a wind mill?

Answer

A. Wind Energy Conversion System : Refer Q. 4.8, Page 123M, Unit-4.

B. Main Criteria for Site Selection :

1. The area should be open and away from cities.
2. Flat open area should be selected, as the wind velocities are high in flat open area.
3. The proposed altitude is to be selected by taking average wind speed data.
4. Minimum wind speed is available throughout the year.
5. Ground surface should be stable and high soil strength.
6. To minimize the transmission losses, the wind power should be near the consumers.
7. It should be atleast 5 km away from the cities to reduce the effect of sound pollution.
8. Low land cost.
9. Approach roads upto site.
10. Height of tower will increase where trees are present.

C. Design Consideration for Wind Turbine : The wind turbine must be able to meet the following criteria :

1. It should be small in size and suitable for roof mounting in urban areas.
2. No risks for its neighborhood.
3. Have good efficiency.
4. Insensitive to turbulence.
5. Suitable for mass production at low price.

Que 4.11. Explain principle of power generation in windmills. Derive an expression for maximum efficiency.

UPTU 2012-13, Marks 10

Answer

A. Principle of Power Generation in Wind Mills :

1. The basic principle of wind energy is to convert the kinetic energy of wind into rotational motion to operate an electric generator.

B. Expression for maximum efficiency :

1. The power in the wind can be extracted by allowing it to pass through moving wings that exert torque on a rotor.

2. The amount of power transferred is directly proportional to the density of the air, the area swept out by the rotor, and the cube of the wind speed.
3. Fig. 4.11.1 shows the air flow diagram on rotor, with variation of wind speed at different sections.

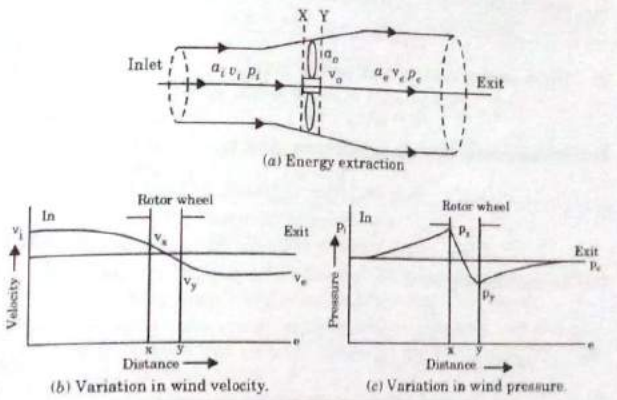


Fig. 4.11.1. Air flow through the rotor.

4. As the air passes through the rotor disk, there is a drop in static pressure such that pressure is below the atmospheric pressure while it leaves the blade.
5. The speed of the wind also gets reduced in the section (wake) and after this section the atmospheric pressure and speed of air again increases.
6. Let a_i and a_e = Inlet and outlet area of air enclosure,
   a_o = Rotor swept volume,
   v_i and v_e = Velocity of wind at inlet and outlet of enclosure,
   v_o = Velocity of rotor,
   ρ = 1.25, air density, and
   $\dot{m}$ = Mass flow rate of air over rotor.
7. The thrust on the turbine by moving air as it passes over the rotor,
$$F = \dot{m}(v_i - v_e) \quad ...(4.11.1)$$
8. The power extracted by turbine,
$$P_T = \dot{m}(v_i - v_e) \times v_o \quad ...(4.11.2)$$
9. Instantaneous loss in kinetic energy of wind as it passes through rotor,
$$P_W = \frac{1}{2}\dot{m}(v_i^2 - v_e^2) \quad ...(4.11.3)$$
10. From equation (4.11.2) and equation (4.11.3),

$$\dot{m}(v_i - v_e) \times v_0 = \frac{1}{2}\dot{m}(v_i^2 - v_e^2)$$

or
$$v_0 = \frac{v_i + v_e}{2} \quad ...(4.11.4)$$

11. From equation (4.11.2) and equation (4.11.4),

$$P_T = \dot{m}(v_i - v_e)\frac{(v_i + v_e)}{2} \quad ...(4.11.5)$$

12. The mass flow rate through turbine rotor,

$$\dot{m} = \rho a_0 v_0 = \rho a_0 \left(\frac{v_i + v_e}{2}\right) \quad ...(4.11.6)$$

13. From equation (4.11.5) and equation (4.11.6),

$$P_T = \rho a_0 \left(\frac{v_i + v_0}{2}\right)(v_i - v_e)\left(\frac{v_i + v_e}{2}\right)$$

$$P_T = \frac{1}{4}\rho a_0 (v_i + v_e)(v_i^2 - v_e^2) \quad ...(4.11.7)$$

14. For maximum power,

$$\frac{\partial P}{\partial v_e} = 0$$

$$3v_e^2 + 2v_i v_e - v_i^2 = 0$$

$$v_e = \frac{1}{3}v_i \quad ; \quad v_e = v_i \text{ (not consider)}$$

$$P_{max} = \frac{8}{27 g_c}\rho A v_i^3$$

$$= \frac{16}{27 g_c} \times \frac{1}{2}\rho A v_i^2 = 0.593 \times \left(\frac{1}{2} \times \frac{\rho A v_i^3}{g_c}\right)$$

$$= 0.593\, P_{total}$$

15. Power coefficient $= C_p = \dfrac{\text{Power output from wind machine}}{\text{Power available in wind}}$

16. The torque on rotor, $T = \dfrac{P_T}{\omega}$, where $\omega = 2\pi N$ ...(4.11.8)

17. The axial force on turbine,

$$F = \dot{m}(v_i - v_e)$$

$$= \rho a_0 \left(\frac{v_i + v_e}{2}\right)(v_i - v_e)$$

$$= \frac{\pi}{8}\rho D^2 (v_i^2 - v_e^2) \quad ...(4.11.9)$$

18. For a given turbine power, lower the angular velocity of rotor, higher the torque and conversely higher the angular velocity lower the torque.

Que 4.12. What is the basis principle of wind energy conversion ?

What methods are used to overcome the fluctuating power generation of wind mill ?

UPTU 2015-16, Marks 10

OR

What methods are used to overcome the fluctuating power generation of a wind mill ? Discuss their merits and demerits.

UPTU 2013-14, Marks 10

Answer

A. Basic Principle of Wind Energy Conversion : Refer Q. 4.11, Page 130M, Unit-4.

B. Methods used to overcome the Fluctuation of Power Generation of a Wind Mill.

1. As the wind speed varies, the speed of the generator varies and produces fluctuations in the electricity.
2. The problems can be solved by following methods.

a. To have constant speed turbines where the blades adjust the pitch, by turning slightly to the side, to adjust with wind speeds.

b. To use variable speed turbines, where the blades and generator change speed with the wind and power control fix the fluctuations of the electrical output.

c. To use low-speed generators.

The various mechanical controls provided with wind machine are as follow :

a. Tethering Control :

1. It is provided with mono and twin blade type horizontal axis turbine to prevent failure because of vibration (fatigue) during orientation of nacelle.
2. The axis of the turbine gets positioned in such a way that the propeller blades revolve in slanting plane at higher speed. The slants get reduced at low speed and get increased at higher speed.
3. This type of control is not provided with three blade rotor.

b. Yaw Control :

1. The yaw control is provided to position the nacelle automatically in the direction of wind with the help of hydraulic mechanism and continuously orient the rotor in the direction of wind.
2. The axis is oriented in such a way that rotor swept area is perpendicular to the wind flowing either in upward or downward direction.

c. Pitch Control :

1. The blade tips are adjusted automatically to provide feathering action. This reduces the speed and power of turbine to match with generator speed.

2. The pitch angle has wide control between $0° - 30°$.

Que 4.13. Write short notes on :

A. Wind characteristics.

B. Environmental impacts of wind energy.

Answer

A. Wind Characteristics :

1. Performance of the wind turbine is determined by non dimensional characteristic curve from which actual performance can be determined.
2. These characteristic curves are :

a. Wind Speed-Power Characteristics :

1. The power output from wind turbines vary with wind speed.
2. The shape of the wind speed-power curve depends upon the rotor swept area, shape of blade, number of blade, tip speed ratio, rotation of rotor, and the cut in rated speed and cut out speed of wind.
3. The area from rated speed to cut-out speed is called the constant power output area and above 25 m/s turbine output starts reducing and finally stops.

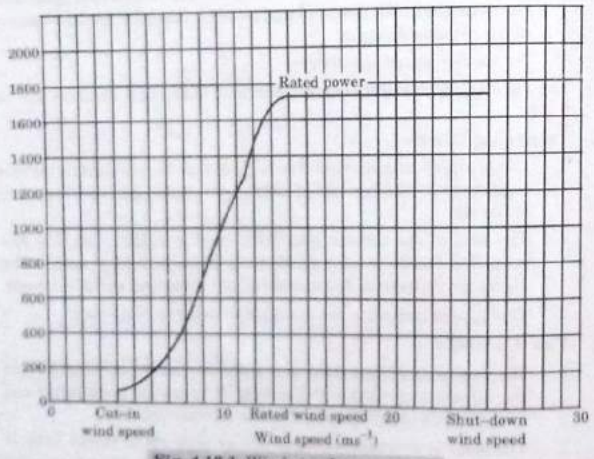


Fig. 4.13.1. Wind speed power curve.

b. Dynamic Characteristics :

1. This characteristic will match the rotational frequency of the turbine for particular wind speed for optimum efficiency.

2. The power extraction will decrease for too close or too apart rotating blade.
3. The maximum value of power coefficient is achieved at particular tip speed ratio.
4. In wind turbine the two extreme conditions of operations, *i.e.*, constant turbine speed or constant tip speed are to be matched to avoid serious effect on turbine.

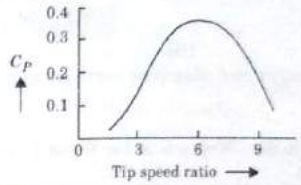


Fig. 4.13.2. Power coefficients to tip speed ratio.

c. Axial Force Characteristics :

1. The variation of thrust force coefficient with tip speed is shown in Fig. 4.13.3.
2. With particular speed ratio, the thrust increases with increased solidity and influences the structural design of the tower.

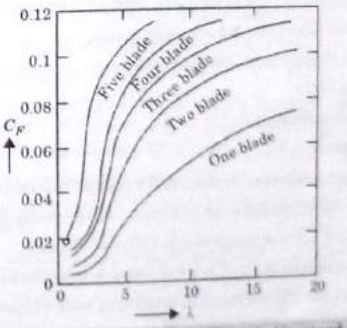


Fig. 4.13.3. Thrust force coefficients-tip speed ratio.

B. Environment Impacts of Wind Energy :

1. Wind energy creates noise pollution because of mechanical (gear box) and aerodynamic noise.
2. The wind turbine produces electromagnetic interference when placed between radio, television etc. stations, as it reflects some electromagnetic radiations.

3. It produces visual shining because of reflection and refraction which depends upon turbine size, number of turbines in wind farm, design etc.
4. Fatal collisions of birds caused by rotating turbine blades.
5. Safety consideration for life because of accidental breaking of blade.

Que 4.14. Describe main consideration in selecting a site for wind farm. Discuss merits and demerits of wind energy.

UPTU 2012-13, Marks 10

OR

What are the advantages and disadvantages of wind energy ?

Answer

A. Considerations in Selecting a Site for Wind Farm : Refer Q. 4.10, Page 129M, Unit-4.

B. Advantages :

1. The electricity generation by wind turbines is pollution free and does not release carbon dioxide.
2. It doesn't involve the consumption of water unlike many other conventional energy sources.
3. It is renewable and available at free of cost.
4. Helpful for supplying energy in rural, offshore, onshore areas.
5. It is reliable and cost effective for large units.
6. Wind does not require any transportation.
7. Low operating cost.
8. Economically competitive.

C. Disadvantages :

1. Wind energy has low power density and variable with time and locations.
2. Wind energy can be useful only at remote areas away from cities.
3. The efficiency of turbine rotor is less (10 – 45 % only).
4. Large transmission losses as the wind farms are located in remote areas.
5. The capital cost per kWh is more in small unit with respect to larger unit (but smaller units are more reliable).
6. Wind cannot be stored as a conventional source.
7. Weight of power system is high and requires large area.
8. Wind energy generates noise pollution.
9. Direction of wind changes and is never constant and reliable.

Que 4.15. What are the applications and limitations of wind energy ?

Answer

A. Applications : The various uses of wind energy are :

a. Electrical :

1. The generators are usually driven through gear box to generate electricity and turbines use low solidity rotor.
2. The energy produced is stored in batteries or can be directly used.
3. The *aero generators* are available upto capacity of 250 kW for small unit.
4. Larger turbines (1–3 MW) are grouped together, which provide bulk power to the electrical grid.

b. Mechanical :

1. Supplying drinking water.
2. Pumping of water at high reservoir.
3. To supply compressed air.
4. Mechanical heat pump.
5. Churning of liquids, milk processing, and greenhouse application.
6. Production of alcohol, cloning materials and rubber processing plants.
7. Food processing industries.
8. Production of plastics and synthesis.
9. Ocean transportation (sail of the ships).

c. Limitations of Wind Energy :

1. Wind turbines work safely between wind speed 5 m/s to 22 m/s. The lower wind speed below 5 m/s needs larger rotor and higher wind above 22 m/s develops large stress on blade and system.
2. The erection of wind turbine is costly because the higher velocity winds are available above 50 m from ground level and need tall tower.
3. Wind farms are to be located in the areas away from tall buildings, tower, cities etc.

5 UNIT

Biomass, OTEC and Wave and Tidal Wave Energy

PART-1

Biomass, Availability of Biomass, and Conversion Theory.

CONCEPT OUTLINE : PART-1

Biomass : Biomass is an organic matter from plants, animals and micro-organism grown on land and water and their derivatives. The energy obtained from biomass is called biomass energy.

Biomass Conversion Processes : Following processes are used for the biomass conversion into energy :

a. Direct combustion,
b. Thermochemical conversion, and
c. Biochemical conversion.

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 5.1. **What do you understand by "biomass" ?**

Answer

1. Biomass refers to solid carbonaceous material derived from plants and animals.
2. These include residues of agriculture and forestry, animal waste and discarded material from food processing plants.
3. Biomass being organic matter from terrestrial and marine vegetation, renews naturally in a short span of time, thus, classified as a renewable source of energy.
4. It is a derivative of solar energy as plants grow by the process of photosynthesis by absorbing CO_2 from the atmosphere to form hexose (dextrose, glucose, etc.) expressed by the reaction.

$$6CO_2 + 6H_2O \xrightarrow[\text{photosynthesis}]{\text{sunlight}} C_6H_{12}O_6 + 6O_2$$

5. Biomass does not add CO_2 to the atmosphere as it absorbs the same amount of carbon in growing the plants as it releases when consumed as fuel.
6. It is a superior fuel as the energy produced from biomass is 'carbon cycle neutral'.
7. Biomass fuel is used in over 90 % of rural households and in about 15 % urban dwellings.

Que 5.2. **Discuss the availability of biomass.**

Answer

1. Biomass is derived from the plant, forest residues, animal dung etc.
2. For use of biomass as energy fast growing trees, sugar, starch and oil containing plants can be cultivated.
3. The cultivated biomass also includes sweet sorghum crops, sugar beets, cereals, herbaceous crops, aquatic crops grown in fresh water, sea water, muddy water etc.
4. Algae are also the source of renewable energy. Algae contain organic matter which can be converted into methane gas. Algae can be cultivated on large scale.
5. Wood and straw come in dry biomass. The energy can be obtained by burning of this biomass.
6. Wood in the form of cut logs, chips, sawdust is commonly used for domestic applications.
7. Straw can be burn in straw burning stoves and furnaces.
8. Energy can also be obtained by converting the organic wastes to intermediate energy such as heat, biogas fuels etc.
9. The wastes can be classified as urban wastes, industrial wastes, animal wastes, forest wastes, fishery and poultry wastes, animal and human excreta and agri-wastes.
10. These wastes may be converted into heat, biogas, and biochemical by various processes such as combustion (as in case of wood, straw etc.), biochemical and biothermal reactions.
11. Biogas contains methane. Biogas plants produce methane by anaerobic digestion.
12. The human waste can also be used for production of biogas.

Que 5.3. **Describe the bioconversion process for obtaining biofuels.**

UPTU 2011-12, Marks 10

OR

Classify biomass conversion technologies. Explain anaerobic digestion process for production of methane.

UPTU 2012-13, Marks 10

Answer

A. Biomass Conversion :

1. The following processes are used for the biomass conversion to energy or to biofuels :

a. Direct combustion,
b. Thermochemical conversion, and
c. Biochemical conversion.

a. Direct Combustion :

1. Combustion is the process of burning in presence of oxygen to produce heat, light and byproducts.
2. Complete combustion to ashes is called incineration.
3. Wood, dung, vegetable waste can be dried and burnt to provide heat or converted into low calorific value gas by pyrolysis.
4. In the pyrolysis process, the organic material is converted to gases, solids and liquids by heating to 500 °C to 900 °C in the absence of oxygen.
5. The combustion of biomass is more difficult than other fuels, since it contains relatively higher moisture content.
6. Biomass is free from toxic metals and their ash.
7. The technology of "fluidised bed combustion" may be used for the efficient combustion of forestry and agricultural waste material such as sawdust, wood chips, bog fuel, rice husks, straws, nutshells and chips.
8. In fluidised bed combustion of biomass, the biomass is fed into a bed of hot inert particles such as sand kept in fluidised state with air at sufficient velocity from below.
9. The operating temperature is normally controlled within the range 750-950 °C; ideally it is kept as high as possible in order to maximise the rate of combustion and heat transfer but low enough to avoid the problem of sintering of the bed particles.
10. The rapid mixing and turbulence within the fluidised bed enables efficient combustion to be achieved with high heat releases, as well as effective transfer, than in a conventional boiler. This can result in more compact boiler with less number of tubes.

b. Thermochemical Conversion :

1. Biomass is decomposed in thermochemical processes having various combinations of temperatures and pressures.
2. Thermochemical conversion takes two forms : Gasification and liquefaction.
3. Gasification takes place by heating the biomass with limited oxygen to produce low heating value gas or by reacting it with steam and oxygen at high pressure and temperature to produce medium heating value gas.
4. The latter may be used as fuel directly or used in liquefaction by converting it to methanol (methyl alcohol), or ethanol (ethyl alcohol) or it may be converted to high heating value gas.

c. Biochemical Conversion :

1. In biochemical conversion there are two principal conversion processes :
   i. Anaerobic digestion, and
   ii. Fermentation

B. Anaerobic Digestion :

1. This process involves microbial digestion of biomass.
2. The process and end products depend upon the micro-organisms cultivated and culture conditions.
3. This process generates mostly methane (CH_4) and CO_2 gas with small impurities such as hydrogen sulphide.
4. The output gas obtained from anaerobic digestion can be directly burnt, or upgraded to superior fuel gas (methane) by removal of CO_2 and other impurities.
5. The residue may consist of protein-rich sludge and liquid effluents which can be used as annual feed or soil treatment after certain processing.

a. Stages of Digestion System :

i. Anaerobic digestion system consists of three stages.

ii. A flow chart showing these stages is given below :

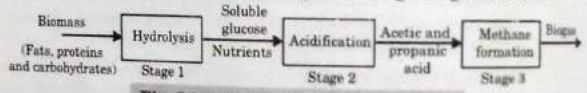


Fig. 5.3.1. Anaerobic digestion process.

Stage 1 : Hydrolysis : In this stage, the complex compounds (such as fats, proteins carbohydrates) are broken into small size compounds through the influence of water enzymes called hydrolysis. The reaction of hydrolysis is given below :

$$(C_6H_{10}O_5)_n + nH_2O \xrightarrow{\text{Enzymes}} n(C_6H_{12}O_6)$$

Cellulose + Nutrients → Soluble glucose + Nutrients

Stage 2 : Acidification : In this stage, the soluble glucose and nutrients are converted in simpler volatile fatty acid and acetic acid as by-product, that accounts for 70 % of methane byproduct with the help of acid forming bacteria.
The reaction of acidification is given below :

$$C_6H_{12}O_6 \xrightarrow[\text{bacteria}]{\text{Acid producing}} 2CH_3CH_2OH\,(\text{Ethylalcohol}) + 2CO_2 + \text{fatty acid} + H_2 + \text{other products}$$

Stage 3 : Methane Formation : In this stage, the methane producing bacteria converts the organic acids into biogas having its main constituents as methane.
The reaction of methane formation is given below :

$$2CH_3CH_2OH + CO_2 \xrightarrow[\text{bacteria}]{\text{Methane producing}} 2CH_3COOH + CH_4$$

$$CH_3COOH \longrightarrow CH_4 + CO_2$$

Note : The biogas production depends on the environment maintained in the digester.

Que 5.4. How does biomass conversion take place ? Name the various models of biogas plant and describe any one of them.

UPTU 2013-14, Marks 10

Answer

A. Biomass Conversion : Refer Q. 5.3, Page 140M, Unit-5.

B. Various Types of Biogas Plants :

1. Movable drum type,
2. Fixed dome type,
3. Continuous type,
   a. Single stage,
   b. Double stage.
4. Batch type biogas plant.

C. Batch Type Biogas Plant :

1. Batch type biogas plants are appropriate where daily supplies of raw waste materials are difficult to be obtained.
2. A batch loaded digester is filled to capacity, sealed and given sufficient retention time in the digester.
3. After completion of the digestion, the residue is emptied and filled again.
4. Gas production is uneven because bacterial digestion starts slowly, peaks and then tapers off with growing consumption of volatile solids. This difficulty can overcome by having minimum two digesters so that at least one is always in operation.
5. This problem can also minimize by connecting batch loaded digesters in series and fed at different times so that adequate biogas is available for daily use.
6. Limitations of batch-fed type biogas plants are :
   a. Gas production in batch type is uneven.
   b. Batch type plants may have several digesters for continuous supply of gas.
   c. Several digesters occupy more space.
   d. This type of plants require large volume of digester, therefore, initial cost becomes high.

e. This plant needs addition of fermented slurry to start the digestion process.

Que 5.5. What is biomass ? How does biomass conversion take place ? Describe the materials used for biogas generation and factors that affect the size of a biogas plant. **UPTU 2015-16, Marks 15**

Answer

A. Biomass : Refer Q. 5.1, Page 139M, Unit-5.

B. Biomass Conversion : Refer Q. 5.3, Page 140M, Unit-5.

C. Material used for Biogas Generation :

1. Biogas is produced by anaerobic decomposition of organic wastes by suitable bacteria. It contains 55- 65 % methane, 30-40 % carbon dioxide and the remainder is impurities like H_2S, N_2, H_2 gases.
2. The main source of production of biogas are crops residue, wet cow dung, vegetable wastes, water hyacinth, algae, poultry or piggery droppings, human waste, etc.
3. Any organic material of animal or plant which is easily biodegradable can be the source of biogas production.

Table 1 : Production of biogas from different types of raw materials.

Material	Amount of gas (m^3/kg)	
	Winter	Summer
Cattle dung	0.036	0.092
Pig dung	0.07	0.10
Poultry droppings	0.07	0.16

D. Factors Affecting the Size of a Biogas Plant :

1. The amount and type of organic waste to be disposed in the digester.
2. Demand of natural gas and consumption pattern.
3. On-site nature of the soil and the level of ground water.
4. Air temperature in the region and wind direction throughout the different seasons.
5. The training level of the staff on farm and home regarding operation of biogas units.

PART-2

Ocean Thermal Energy Conversion, Availability, Theory and Working Principle, and Performance and Limitations.

CONCEPT OUTLINE : PART-2

Ocean Thermal Energy Conversion : It is a means of converting ocean thermal energy into useful energy. OTEC is a technology that converts solar radiation into electric energy. It uses the ocean's temperature gradient (The oceans layers of water have different temperatures) to generate the power, based on second law of thermodynamics.

OTEC System : There are three basic types of OTEC power plant cycle :

1. Open cycle,
2. Closed cycle, and
3. Hybrid cycle.

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 5.6. What is the working principle of ocean thermal energy conversion ?

Answer

1. The principle of ocean thermal energy conversion (OTEC) is that there is a temperature difference between water at the bottom of the sea and the water at the top.
2. This temperature difference can be used to operate a heat engine and most of the radiation is being absorbed at the surface layer of water.
3. The mixing between hot and cold water is prevented because no thermal convection occurs between hot and cold water layer. This means that the surface layer will act as a source and cold layers act as a sink.
4. Therefore, it is essential to connect the reversible heat engine between source and cold sink to produce work that can be converted into required applications.
5. The absorption of solar radiation in the water varies and can be expressed by Lambert's law :

$$-\frac{dI_y}{dy} = \mu I$$

$$I_y = I e^{-\mu y}$$

or,

Where, I_y = Radiation intensity at depth y from water surface and falls exponentially with depth,

I = Radiation intensity at water surface, and

μ = Extinction or absorption coefficient.

Que 5.7. What is the efficiency of OTEC ?

Answer

1. The maximum possible efficiency of a heat engine working between two temperature limits can not be more than that of a Carnot cycle operating between the same temperature limits.
2. In the range of temperatures of warm water (T_1) in the upper surface layer and cold water (T_2) in the depth of the tropical ocean, the Carnot cycle efficiency is given by

$$\eta = 1 - \frac{T_2}{T_1}$$

If, $T_1 = 27\ °C$

or $T_1 = 27 + 273 = 300\ K$

$T_2 = 5\ °C$

or $T_2 = 5 + 273 = 278\ K$

Then Carnot efficiency is

$$\eta = 7.33\ \%$$

3. The actual efficiency of an OTEC power plant is less than the Carnot cycle and it is given by

$$\eta_{OTEC} = EF \times \eta_c$$

Where, η_c = Carnot cycle efficiency, and

EF = relative efficiency factor (0.4 to 0.6).

Que 5.8. What are the types of OTEC system ?

OR

Describe the basic principle of ocean thermal energy conversion system. Describe the "Open Cycle" ocean thermal energy conversion system.

UPTU 2013-14, Marks 10

Answer

A. Principle of OTEC : Refer Q. 5.6, Page 145M, Unit-5.

B. Types of OTEC System :

1. There are two basic types of OTEC systems :
   a. Closed cycle system or Anderson cycle system, and
   b. Open cycle system or Claude cycle system.

a. Closed or Anderson Cycle OTEC System :

1. In this system, the working fluids for heat engines use the fluids like ammonia, freon 12, butane gas having low boiling point because the working temperature of sea water is small.
2. Warm water from ocean surface is circulated through a pump to a heat exchanger which acts as boiler to generate freon vapour at high pressure.
3. This vapour expands in the turbine to develop mechanical power and it is used to drive an electric generator which produces electric energy.
4. Freon vapour from turbine at low pressure is condensed in the condenser with the help of cold water drawn from the depth of ocean through a pump. The overall efficiency of such plant is very low in the range of 2 to 3 % only.

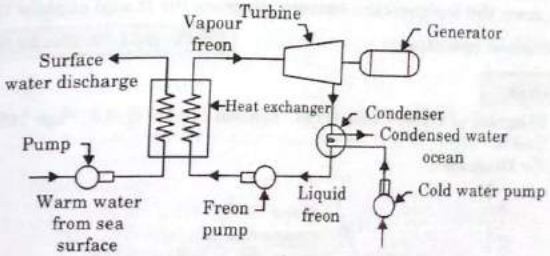


Fig. 5.8.1. Closed or Anderson cycle OTEC plant.

b. Open Cycle or Claude Cycle OTEC System :

1. In this system, the warm water from ocean surface is admitted through the deaerator to the flash evaporator which is maintained under high vacuum.
2. As a result, a low pressure steam is generated due to throttling effect and the remainder liquid is discharged back to the ocean at high depth.
3. The deaerator also removes the dissolved non-condensable gases from water before supplied to the evaporator.
4. This low pressure steam having very high specific volume is supplied to turbine where it expands and the mechanical power so developed is converted into electrical power by the generator.
5. The exhaust steam from turbine is discharged into a direct contact type heat exchanger and mixes with the cold water drawn from ocean at a depth of about 1 to 2 km.
6. The mixture of condensed steam and ocean cold water are discharged into the ocean.

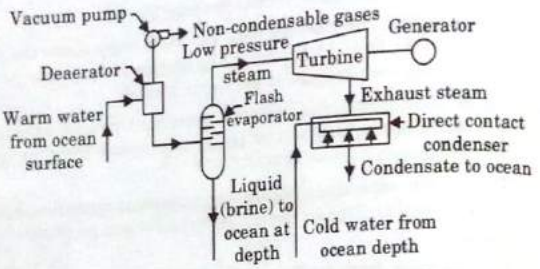


Fig. 5.8.2. Open or Claude cycle OTEC system.

Que 5.9. **Draw the schematic diagram of open cycle OTEC system. Also draw the temperature-entropy diagram for it and explain the principle of operation.** **UPTU 2011-12, Marks 10**

Answer

A. Diagram of Open Cycle OTEC System : Refer Q. 5.8, Page 146M, Unit-5.

B. *T-s* Diagram :

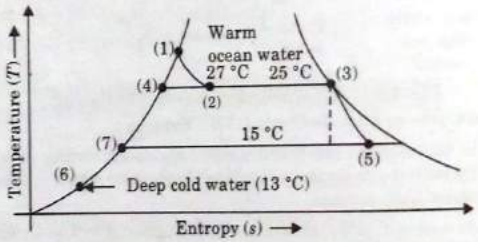


Fig. 5.9.1. T-s diagram of open cycle OTEC system.

C. Principle of Operation : Refer Q. 5.6, Page 145M, Unit-5.

Que 5.10. **What are the environmental effects of OTEC ?**

Answer

The OTEC system possess some environmental impacts as compared to traditional power plant :

1. The marine environment gets affected by these plants through water heating.
2. Release of toxic chemical and entrapment of small sea organism in intake pipes is common.

3. Thermal layer of sea water near the plant gets disturbed because of discharge of low and high water at intermediate layer.
4. Affects the marine environment because of change in salinity, dissolved gases, nutrients, carbonate etc.
5. Large discharge of mixed water below the ocean surface for long time will change the environment for hatching the eggs and lower down the production rate of fishes, corals etc.
6. Toxic chemicals from the plant may leak to the environment and kill the local marine organisms.
7. The marine life gets affected because of change in pH value and dissolved oxygen.

Que 5.11. **Give the advantages, disadvantages and applications of OTEC.**

Answer

A. Advantages :

1. The thermal resource of the ocean ensures that the power source is available during day or night.
2. It is eco-friendly.
3. It eliminates the need for a surface heat exchanger.
4. It produces potable water which reduces electrical generating costs up to one-third.

B. Disadvantages :

1. Due to low pressure, large size of steam turbine is used.
2. It needs very large vacuum pumps.
3. In closed cycle the working fluid is expensive.
4. Cost of plant is high.
5. Cost of electrical energy from open cycle OTEC is very high.
6. Corrosion of metal parts due to saline water.
7. Size of the plant is limited due to large size of the components.
8. Construction of floating power plant is difficult.

C. Applications :

1. A closed cycle OTEC plant can also act as a chemical treatment plant.
2. An OTEC plant can also be used to pump up the deep sea water and this cold water is used for cooling green houses, and air conditioning systems etc.
3. The enclosing area of OTEC can be used for aquaculture and mariculture.
4. The deep sea cold water is rich in nutrient and can be used for various applications.

Que 5.12. **Write short note on "thermoelectric OTEC".**

Answer

A. Thermoelectric OTEC :

1. This OTEC system was developed by Solar Energy Research Institute Colorado USA, during 1979 and it operates on the thermoelectric principle which is simple in construction and economical.
2. Semiconductors are used to design two separate packs covered by a thin thermal conducting sheet.
3. Warm water from the surface of the ocean is circulated over one device and the cold water pumped from the depth of the ocean is allowed to flow over the other device.
4. The temperature difference between two water with the help of solid state semiconductor devices generates the electric power.
5. The OTEC plant economy is dependent on large variation of water temperature used from the surface and the deep ocean.

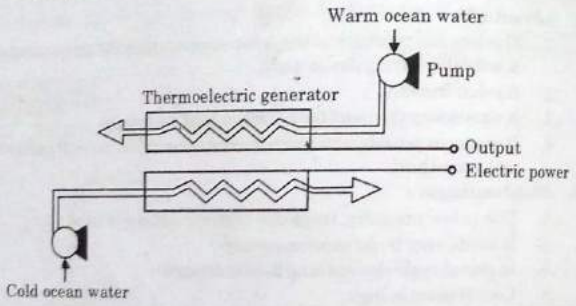


Fig. 5.12.1. Thermoelectric ocean thermal energy conversion equipment.

Que 5.13. What are the limitations of OTEC ?

Answer

1. Low thermal efficiency (2 – 3 %) because of low temperature difference of water available.
2. The capital cost is more.
3. Large size pump is required to handle large volume of water.
4. Plant should be capable of withstanding severe ocean storms and seasons.
5. Components life is short because of corrosion and erosion by ocean water.
6. Plant size above 100 MW is limited because it requires large size component (requires 30 m diameter pipe of 1 km long).

7. Difficult maintenance.
8. Construction of floating plant is difficult.

PART-3

Wave and Tidal Wave, Principle of Working, Performance and Limitations, and Waste Recycling Plants.

CONCEPT OUTLINE : PART-3

Wave Energy : Wave energy derives from wind energy, which derives in turn from solar energy. Waves are formed on the surface of water by the frictional action of the winds resulting in the radial depression of energy from the blowing winds in all directions.

Tidal Wave Energy : Tides are generated by the action of gravitational force of the sun and the moon on the ocean's surface, by the spinning of the earth about its axis and the relative positions of the earth, the moon and the sun.

Ocean tides are the periodic rise and fall of ocean water level occurring twice in each lunar day. The tidal rise and fall of water is accompanied by periodic horizontal to and fro motion of water called tidal currents. The tidal currents flow in horizontal direction and have kinetic energy. This energy is called tidal current energy.

Waste : Generation of waste by human and animal activities is unavoidable. The different types of waste we generate may be biodegradable or non-biodegradable and are discarded as useless and unwanted. The waste may be hazardous or non-hazardous and can be recyclable or non-recyclable.

Different Types of Waste : The different types of waste are :

a. **Solid Waste :** The solid waste from different resources fall in this category.
b. **Liquid Waste :** The liquid cleaner, detergents, paints, medicine etc., fall in this category.
c. **Gaseous Waste :** Home, and factories burn fuel to produce heat and harmful gases etc., fall in this category.

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 5.14. Discuss the working principle of wave energy conversion system.

Answer

1. Ocean waves are created by wind interaction with the ocean surface and are an indirect form of utilizing the solar energy, because the wind is created by pressure differences in the earth atmosphere, due to unequal solar heating.
2. The energy transferred to water by wind is kinetic as well as potential energy and it depends upon the wind speed, blowing time of wind, and distance of wind travel over the sea.
3. The blowing wind creates a pressure over the surface of ocean water and air pushes down each particle, which again comes up. So, it actually moves up and down in circular path.
4. Every particle passes on its motion to the next. This movement of the water particles produces a pattern, which we see as wave.
5. These waves travel a long distance as they propagate and are continuously strengthened by the new wind as they pass and retain their energy even winds die down.
6. The ocean wave energy is created because of periodic to and fro, up and down motion of water particles in the form of progressive waves.
7. It is an important to note that water does not travel with wave while the disturbance or wave travels in wind direction.
8. The height of the wave depends on the speed of the wind.
9. These waves develop for few seconds and get superimposed on ocean water.
10. The power potential of these waves can be converted to electricity by mechanical means and harnessing this oceanic energy of waves has been developed over past 30 years using wave machines.

Que 5.15. Explain the devices used for wave energy conversion.

Answer

1. The wave energy systems constructed with flexible moorings and transmission cable as the devices are floating type and float near or at the surface of ocean to extract maximum power of incident wave.
2. The most promising devices to meet the demand of local coastal areas are :

A. Hose Pump :

1. This device consists of elastomeric hose, which reduces its volume when stretched.
2. The system floats near the surface by means of float.
3. While oscillating with the surface waves, the water gets pressurized in the hose and is fed to the turbine runner placed at bottom of hose through non returnable valve.

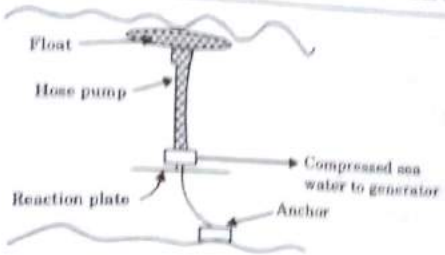


Fig. 5.15.1. Hose pump system.

B. Pelamis :

1. The pelamis device is intended for general deployment in off shore and is designed to use technology already available in the offshore industry.
2. It is composed of hollow cylindrical sections joined by hinged joint.
3. The energy is extracted by hydraulic rams as waves run down the length of the device and actuate the joints that drive hydraulic motor via an energy-smoothing system.
4. The full-scale version has a continuously rated power output of 0.75 MW.
5. The slack-moored device will be around 130 m long and 3.5 m in diameter.
6. Electricity generated in each joint is transmitted to shore by a common transmission cable.

C. Oscillating Water Column Device :

1. The oscillating column of water pushes the air above the water column and these oscillations of air are transferred to the air turbine connected to it.

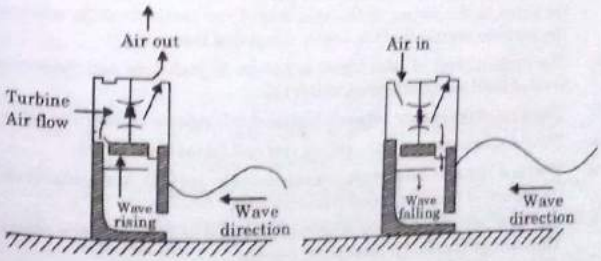


Fig. 5.15.2. Oscillating water column device.

2. The atmospheric air moves inside the column when waves fall and goes out when waves rise.

3. The velocity of air oscillating can be further increased by decreasing the cross-sectional area of the channel through which air passes the turbine and becomes an added advantage.

Que 5.16. What are the advantages and disadvantages of wave energy ?

Answer

A. Advantages :

1. It is a concentrated form of energy and can naturally accumulate over time.
2. It is an eco-friendly renewable source of energy.
3. No space coverage on land as required by wind and solar devices.
4. Large concentrated power carried in wave's motion.
5. The running cost is negligible as this energy is available free of cost.

B. Disadvantages :

1. The device operates in ocean and needs consideration for construction, maintenance, and reliability.
2. Wave machines have to withstand the sudden storm and other climate that develop fatigue stress on the system and decrease its life.
3. Capital cost of system is high.
4. Problem in maintenance occurs.

Que 5.17. What do you understand by "tidal energy" ?

OR

What are tides ? How they are formed ?

Answer

1. Tides are generated by the action of gravitational forces of the sun and the moon in the ocean, by the spinning of the earth about its axis and the relative positions of the earth, moon and the sun.
2. The highest level of tidal water is known as high tide and the lowest level of tidal water is known as low tide.
3. The level of difference between high and low tides is called tidal range.
4. The tides are the periodic vertical rise and fall of ocean water.
5. The tidal rise and fall of water accompanied by periodic horizontal to and fro motion of water is called tidal currents.
6. The tidal currents flow in horizontal direction and have kinetic energy. This energy is called tidal current energy.
7. The rise and fall of the water level follows a sinusoidal curve.
8. Point *A* indicates the high tide point and *B* indicates low tide point.

9. The tidal range (R) is the difference between consecutive high tide and low tide water levels,

R = (High tide level) – (Low tide level)

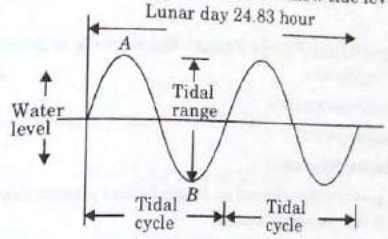


Fig. 5.17.1.

Que 5.18. Explain the principle and components of tidal power plants. Also, discuss the working of tidal power plants.

OR

Explain with sketches the various methods of tidal power generation. Write the advantages and limitations of tidal power.

UPTU 2015-16, Marks 10

Answer

A. Principle : To utilize tidal energy, water must be trapped at high tide behind a dam or barrage and then made to drive turbine as it returns to sea during low tides. The available energy is proportional to the square of the amplitude.

B. Components of Tidal Power Plant :

Main components of a tidal power plants are :

a. Barrage,
b. Sluice gates,
c. Turbine, and
d. Basin.

a. Barrage : It is a dam of low head and requires the following features :

1. Less sloppy towards the ocean and basin side.
2. It should be able to withstand the shock load of tides and wave.
3. Low height and shorter in length to minimize the cost of construction.
4. Steel foundation frame and channels are embedded in the ducts within the barrage for turbine and gates steel foundation.

b. Sluice Gates : These gates are opened by water pressure and no mechanical means is required.

c. **Turbine :** The Kaplan or bulb type turbine is used to operate with low head and the entire turbine generator unit is submerged in the water.

d. **Basin :** The basin can be single, pair or multiple type and have different designs.

C. **Working of Tidal Power Plant :** The working is described according to the type of basins.

a. Single basin system, and

b. Double basin system.

a. Single Basin System :

1. In a tidal power plant (based on single basin system), the power house is situated at the mouth of basin.
2. The hydraulic turbine in the power house only operates during the discharge of water from the basin during ebb tide and during the high tide the basin is again filled.
3. The direction of flow through the turbine during the ebb and flood tides alternates and generation of power is accomplished, both during the emptying and filling cycle of basin.
4. Though the double cycle system has only short duration interruptions in turbine generator operation, but the continuous power generation is still not possible.
5. Further, the power generation coincides occasionally with the peak power demands. This problem is overcome in double-basin system.

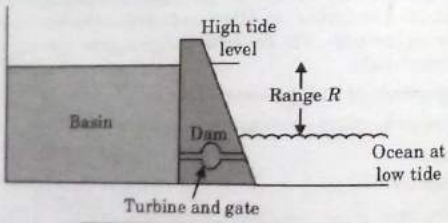


Fig. 5.18.1. Single basin system.

Energy and Power in Single Basin System :

1. Let,
   R = Tidal range,
   m = Mass flowing through turbine,
   W = Work done,
   A = Surface area of basin,
   H = Intermediate head,
   dH = Small head,
   g = Gravitational constant, and

   ρ = Density of water.

2. $dw = gH\,dm$

   But, $dm = -\rho A\,dH$ $\left(\because \text{Density} = \frac{\text{Mass}}{\text{Volume}}\right)$

   $\therefore$ $dw = -\rho AgH\,dH$

3. Total work during emptying of filled basin,

$$W = \int_R^0 dw = \int_R^0 -\rho AgH\,dH$$

$$W = \frac{1}{2} g\rho AR^2$$

$$W \propto R^2$$

Therefore, the work is proportional to square of the tidal range.

4. Average power $(P_{avg}) = \frac{W}{t}$

   Where $t = 6\text{ h } 12.5\text{ min} = 22350\text{ sec.}$

   $\therefore$ $P_{avg} = \frac{g\rho AR^2}{2 \times 22350} = \frac{1}{44700} g\rho AR^2$

5. Assuming density of sea water = 1025 kg/m^3, the average power per unit basin area,

$$\frac{P_{avg}}{A} = \frac{1}{44700} \times 9.8 \times 1025R^2 = 0.2247R^2 \text{ W/m}^2$$

b. Double Basin System :

i. Construction :

1. This system has two basins at different levels and a dam is provided in between these basins.
2. Inlet and outlet sluice gates are provided in the dam and the water level in upper basin is maintained above the level of water in the lower basin.

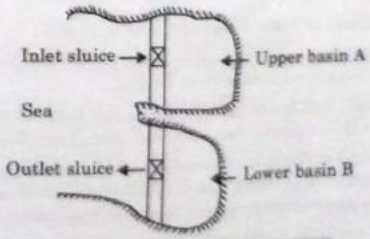


Fig. 5.18.2. Double basin system.

ii. Working :

1. When the water level in upper basin is maximum during high tide, the inlet sluice is closed and the level of water in lower basin keeps on rising due to discharge of water by the turbine.
2. When the level of water in lower basin equals during the ebb tide, the outlet sluice is opened and it is closed when the water level reaches to its minimum level which is equal to the level of water in upper basin.
3. Again the inlet sluice is opened and the cycle is repeated.

D. Advantages of Tidal Power :

1. Protection of coastline against damage from high storm tides by providing a barrage.
2. The main advantage of tidal power plant is that it is inexhaustible.
3. It produces electricity reliably.
4. It is unaffected by the changing mood of the nature such as failure of monsoon.
5. It is pollution free.

E. Limitations of Tidal Power :

1. Initial capital cost of plant is very high and needs long constructional period.
2. Output power is variable due to uneven operation.
3. Sea water is corrosive.
4. Sedimentation of basin is a serious problem.
5. Due to variable tidal range, the efficiency of plant is affected.
6. Marine life is affected.

Que 5.19. State the present status of tidal power plants in India. Why is the tidal energy not being utilized ?

UPTU 2011-12, Marks 10

Answer

A. Present Status of Tidal Power Plants in India :

1. The possible tidal sites identified in India are Gulf of Cambay, Gulf of Kutch and Sunderban area of West Bengal.
2. The tide height is 10.8 m at Gulf of Cambay and the probable potential is 15 MW from this site but it has a problem of high silt deposit.
3. The tidal height at Kutch is 7.5 m and it is estimated that power potential from these sites will be better than Gulf of Cambay, with low silt deposits (1000 ppm), as per survey carried out and may prove to be a better location.

4. The tide height at Sunderban areas is about 4.8 m, less than other two sites but it is anticipated that power of 40 MW can be developed from such site.
5. Since, India is surrounded by sea on its three sides, its potential to harness tidal energy has been recognized by the government of India and three sites (Gulf of Cambay, Gulf of Kutch and Ganges Delta in the Sunderban) indentified as potential areas for tidal power generation.
6. The most attractive locations are the Gulf of Cambay and the Gulf of Kutch on the west coast where the maximum tidal range is 11 m and 8 m with an average tidal range of 6.8 m and 5.2 m respectively.
7. The Ganges delta in the Sunderbans in West Bengal also has the maximum tidal range 4.8 m with an average tidal range of 2.97 m and is a good option for small scale tidal power plant.
8. The identified economic tidal power potential in India is of the order of 8000-9000 MW with about 7000 MW in the Gulf of Cambay, about 1200 MW in the Gulf of Kutch and less than 100 MW in Sunderbans.
9. The Kutch tidal power project with an installed capacity of about 900 MW is estimated to cost about Rs. 1460/- crore with generating electricity cost about 90 paisa per unit.
10. The techno-economic feasibility report is now being examined by West Bengal's 100 MW tidal power project, the first of its kind in the country with a generation capacity of 3.6 MW, to harness ocean energy through the tidal route using the barrage technology as this has been found successful in France, Canada, Russia and China.
11. The project will comprise of two barrages built across the upstream and downstream ends of the Durgaduani, which runs between the Islands of Gosaba and Bali-Bijayanagar and connects the Bidyadhari and Gomdi rivers.
12. A bypass canal built at the downstream end will have a powerhouse and sluice gates.
13. A project based on Norway technology for harnessing ocean energy through water current turbine technology by revolving the blades of a windmill-like turbine standing on the sea bed is currently in the experimental stage in India.

B. Reasons for not Utilizing Tidal Energy :

1. Due to variation in tidal range, the output is not uniform.
2. Since the turbines have to work on a wide range of head variation (due to variable tidal range) the plant efficiency is affected.
3. There is a fear of machinery being corroded due to corrosive sea water.
4. It is difficult to carry out construction in sea.
5. As compared to other sources of energy, the tidal power plant is costly.
6. Sedimentation and siltation of basins are the problems associated with tidal power plants.

7. The power transmission cost is high because the tidal power plants are located away from load centres.

Que 5.20. How can tidal power be utilized for the benefits of mankind ?

Answer

A. Benefits of Mankind : There would be a number of benefits :

1. Protection of coastline against damage from high storm tides by providing a readymade road (barrage).
2. It produces no greenhouse gases or other waste.
3. It needs no fuel and tides are predictable.
4. It produces electricity reliably.
5. Less maintenance cost.
6. Tides are totally predictable and tides rise and fall every day in a very consistent pattern.
7. Offshore turbines and vertical-axis turbines are not expensive to build and do not have a large environmental impact.
8. A plant has long life of 75 to 100 years, in comparison with the 35 years of a conventional fossil fuel plant.
9. Besides the economical factors, tidal energy is clean and renewable, unlike fossil fuels.

Que 5.21. What do you mean by recycling ?

Answer

1. Recycling involves a series of processes, which includes collection of recyclable materials and sorting out and using it as raw material after palletizing.
2. It also includes processing, manufacturing and selling of final products.
3. The collected materials are sorted and cleaned out for manufacturing into two products.
4. Some of the household materials, which can be recycled and used further, include newspapers and paper towels, aluminum, plastic and glass, soft drink containers, steel cans, and plastic laundry bottles.
5. The reuses of recycled material are fall in the field of recovered glass, in roadway asphalt or recovered plastic in carpeting, park benches, and pedestrian bridges.

Que 5.22. What are the advantages and disadvantages of recycling of waste ?

Answer

A. Advantages of Recycling of Waste :

1. The amount of waste which goes for disposal reduces.
2. The amount of raw material to produce a new product reduces.
3. It results in healthier environment by reducing the amount of waste and later effects due to non-biodegradable substance like plastics.
4. It reduces the further exploitation of fossil fuels.
5. It reduces the amount of embodied energy spent to produce a new product.
6. Recycling can reduce the emission of greenhouse gases.
7. It reduces the cost of recycled product as compared to new product.
8. It provides job for waste pickers.

B. Disadvantages of Recycling of Waste :

1. The reprocessing of recovered materials is not always pollution free.
2. The effects of de-inking and re-pulping waste paper are relatively important in assessing the environmental effects as recycling of paper produces salt in the environment.
3. The costs of collection, transport and reprocessing are higher.
4. A great deal of effort goes into extending the recycling of materials (packaging) which accounts for only one tenth of total urban waste by weight.

Que 5.23. What do you understand by waste recycling management ? What are the basic steps involved in waste management by different sources ?

Answer

A. Waste Recycling Management :

1. Waste recycling management is the part of energy conservation.
2. The typical route for recycling the waste material involved is collection, transport, processing and/or disposal of waste materials.
3. Recycling plays a major role in waste management. Though it is an uncommon activity, it earns good income in developing countries.

B. Steps Involved in Waste Management :

1. The various steps included in waste recycling management are :
   a. Find out the various alternate waste recycling options.
   b. Listing of steps included in the process.
   c. Economical analysis of recycling process.
   d. Organising.

e. Execution and monitoring of program.

2. The hazardous waste is to be disposed off in a properly lined landfill or containers to prevent serious health effects.
3. The biodegradable waste goes for composting or biomethanation (biogas) process to produce energy and the remaining goes for land filling.
4. The reuse of material like glass, plastics reduces the wastes considerably after recycling into new products, plastics which can be molded to usable material.
5. The wood and agricultural residues are used to produce biomass briquettes.